

**HYDROMETEOROLOGICAL REPORT NO. 56**

**Probable Maximum and TVA Precipitation Estimates  
With Areal Distribution for Tennessee River  
Drainages Less Than 3,000 Mi<sup>2</sup> in Area**

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**Silver Spring, Md.**  
**October 1986**



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PROBABLE MAXIMUM AND TVA PRECIPITATION ESTIMATES WITH AREAL DISTRIBUTION  
FOR TENNESSEE RIVER DRAINAGES LESS THAN 3,000 MI<sup>2</sup> IN AREA

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**ABSTRACT** This study provides probable maximum precipitation (PMP) and TVA precipitation estimates for durations of 6 to 72 hr and areas of 1 to 3,000 mi<sup>2</sup> for basins located in the Tennessee River Watershed. The first part gives procedures for estimating PMP and TVA precipitation for small basins (<100 mi<sup>2</sup>) for durations of 6 to 24 hr, while the second part gives procedures for estimating PMP and TVA precipitation for large basins (100 mi<sup>2</sup>-3,000 mi<sup>2</sup>) for durations of 6 to 72 hr. Specific PMP and TVA precipitation estimates are presented for 26 basins in the Tennessee River Watershed.

Procedures are also presented to compute the areal distribution of PMP and TVA precipitation. This includes the areal distribution in concurrent drainages to the main subbasin.

Finally, precipitation amounts antecedent to the maximum 24-hr and 3-day storm (both PMP and TVA precipitation) are derived.

## 1. INTRODUCTION

### 1.1 Purpose

The purpose of this report is to provide updated estimates of probable maximum precipitation (PMP) and Tennessee Valley Authority (TVA) precipitation for area sizes up to 3,000 mi<sup>2</sup> for the Tennessee Valley region. Additional information on antecedent rainfall criteria is also provided. As such, this report supersedes Hydrometeorological Report (HMR) No. 45 (Schwarz and Helfert 1969), [hereafter, all reports in this series will be referred to as HMR No. ]. This report brings together into one document all revisions, modifications and changes, such as the Addendum (Schwarz 1973). In addition, the report has been expanded to include procedures for estimating precipitation over concurrent drainages.

### 1.2 Background

Generalized estimates of 1- to 72-hr PMP and TVA precipitation for basins ranging between 5 and 3,000 mi<sup>2</sup> in the Tennessee Valley watershed were provided in HMR No. 45. However, recent hydrometeorological studies for other locations have indicated that some of the concepts used in the development of HMR No. 45

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can be further extended. In addition, our knowledge of the interaction of terrain with storm dynamics for short durations and small areas has improved.

The initial study separated procedures used to develop PMP estimates for areas equal to or less than 100 mi<sup>2</sup> and greater than 100 mi<sup>2</sup>. The procedures were based upon the predominant storm type producing extreme precipitation amounts for these ranges of area sizes. This separation resulted in significantly different PMP estimates for basins that differed by only a few square miles in area. A review of this problem in 1973 revealed that the differences resulted from an inadequate consideration of the effects of convective activity for areas just somewhat larger than 100 mi<sup>2</sup>. An Addendum (Schwarz 1973) provided procedures to resolve this problem.

A discussion of the concept of PMP and some of the practical problems of estimating PMP are discussed in HMR No. 41 (Schwarz 1965). A more detailed discussion may be found in Weather Bureau Technical Memorandum HYDRO-5 (Myers 1967). More recent studies, such as HMR No. 51, "Probable Maximum Precipitation Estimates, United States East of the 105th Meridian," (Schreiner and Riedel 1978), HMR No. 52, "Application of Probable Maximum Precipitation Estimates - United States East of the 105th Meridian" (Hansen et al. 1982), and HMR No. 55, "Probable Maximum Precipitation Estimates, United States Between the Continental Divide and the 103rd Meridian" (Miller et al. 1984a), provide evolutionary ideas that have influenced the development of this report. In addition, procedures to compute areal distributions of PMP and TVA precipitation in mountainous areas where orographic effects are important have been included in this report.

Any need for PMP estimates for basins larger than 3,000 mi<sup>2</sup> must be met by individual basin studies (e.g., Schwarz 1961, Schwarz 1965) or by a future generalized study.

### **1.3 Authorization**

The authorization for this study are agreements between the Tennessee Valley Authority and the National Weather Service in 1966, 1982, 1983 and 1984.

### **1.4 Concept of PMP and TVA Precipitation**

The definition of PMP used in the present report is the same as that used in HMR No. 52, namely, "Theoretically the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location at a certain time of the year." This definition represents a slight change from that used in HMR No. 45, and results in a need to follow procedures outlined in HMR No. 52, and described in chapter 4 of this report, to convert storm PMP to basin-averaged PMP.

The large analyzed sample of extreme storms experienced in the United States has provided a few storms assumed to have produced precipitation from water vapor in the atmosphere with near optimum efficiency. In such cases, nature can be looked upon as performing all the necessary integrating of rain-producing factors except for some slight upward adjustment for moisture charge. Such rare storms are transposed to adjoining regions. In the present report, the general level of the small basins PMP is controlled by a few such storms, e.g., --the

Smethport, PA storm of July 17-18, 1942--which dumped over 30 in. of rain in less than 6 hr just to the northeast of Smethport, PA.

The general level of nonorographic PMP for the larger basins is based upon the moisture maximization and envelopment of major storms of record that are transposable to some portion of the Tennessee River basin. Among the more important storms are those centered near Altapass, NC in July 1916, Boyden, IA in September 1926, Warner, OK in May 1943, Tyro, VA in August 1969 and Zerbe, PA in June 1972.

Like the PMP, the TVA precipitation concept from HMR No. 41 is preserved in the present report. Basically, the TVA precipitation is defined as the level of precipitation resulting from transposition and adjustment (without maximization) of outstanding storms, which have occurred elsewhere in the Tennessee Valley. A few of the most extreme events are undercut. In this report, in order to make the TVA precipitation estimates agree with actual storm experience, the variable depth-duration concept given in HMR No. 45 is continued here, which, for example, recognizes that at the TVA level of precipitation, there is little chance that the maximum 72-hr storm event also includes the maximum 6-hr rainfall event.

### 1.5 Organization of Report

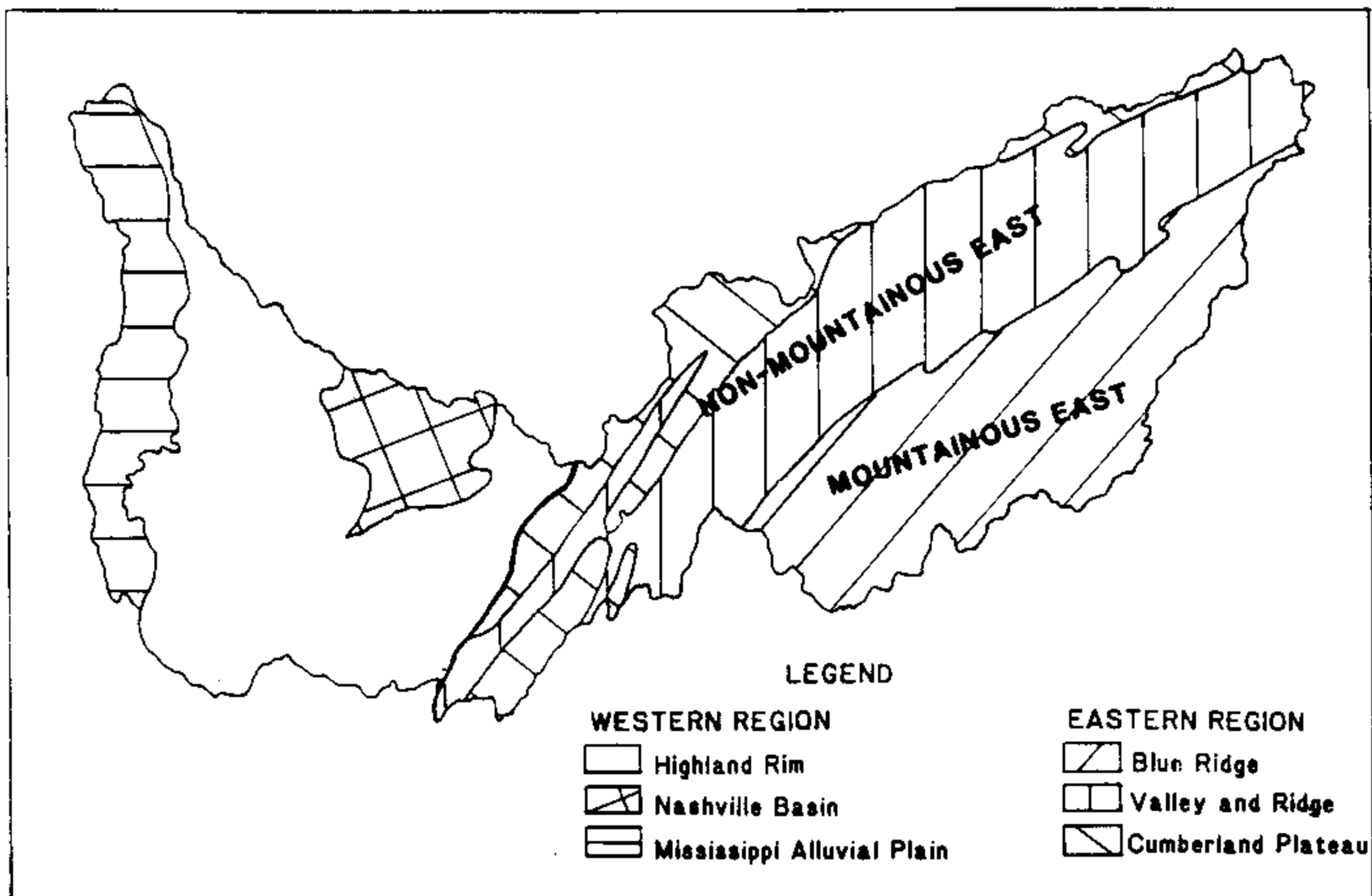
Chapter 2 describes the development of 24-hr PMP and TVA precipitation for basins up to 100 mi<sup>2</sup>. Generalized procedures for estimating precipitation up to 72 hr for basins between 100 mi<sup>2</sup> and 3,000 mi<sup>2</sup> are the subject of chapter 3. Chapter 4 discusses areal distribution of PMP and TVA precipitation for all area sizes considered in this report. In chapter 5, stepwise procedures for computing PMP and TVA precipitation and the areal distribution are presented together with examples. PMP and TVA precipitation estimates for 26 basins in the Tennessee River watershed are given in chapter 6. Finally, chapter 7 describes the development of antecedent precipitation criteria.

Throughout this report there are a number of figures that are considered "working diagrams," i.e., they are important for use in making computations of PMP and TVA precipitation according to the procedures outlined in chapter 5. Since the information on these selected figures is critical to the accuracy with which the answer can be determined, a set of oversized figures (approx. 1:825,000) have been prepared. Anyone having an interest in these oversized diagrams should contact the Tennessee Valley Authority.\*

### 1.6 Broadscale Topographic Features of the Tennessee Watershed

The Tennessee River watershed can be divided into essentially four topographic subregions: Western Basin, Cumberland Plateau, Valley and Ridge, and Blue Ridge, shown in figure 1. The Western Basin includes the Mississippi Alluvial Plain, Highland Rim and the Nashville Basin (fig. 1). The Western basin is relatively low, with rolling hills and is generally referred to as the Western region in this report. The Cumberland Plateau is not a flat plateau, but characterized by irregular highlands and ridges which are particularly steep along the edge. The Valley and Ridge subregion is comprised of parallel ridges running from southwest to northeast. The Cumberland Plateau and the Valley and Ridge subregions combine

\* c/o Flood Protection Branch, Hydrology Section  
200 Liberty Building, Knoxville, TN 37902



**Figure 1.--Generalized physiographic provinces of the Tennessee River watershed.**

to represent the non-mountainous east in this report. The Blue Ridge subregion, which forms the mountainous east in this report, is bounded by: (1) the mountains which form the eastern and southern boundary of the Tennessee Valley watershed and (2) the Unakas and Great Smoky Mountains, which run from the southwest through the northeast along the northwestern boundary of the region and reach elevations exceeding 6,000 ft.

With regard to broadscale controls on storm rainfall, the mountains in the Blue Ridge subregion in figure 1 provide localized sheltering to the interior of the mountainous east and the Valley and Ridge region from significant moisture inflow from the south and east. The Cumberland Plateau shelters the Valley and Ridge and western slopes of the southern Blue Ridge from storms moving from the west. The Western Basin is relatively free from any broadscale sheltering.

In this report, the Western Basin will generally be referred to as the western TVA region, while the other three provinces (Cumberland Plateau, Valley and Ridge, and Blue Ridge) represent the eastern TVA region. The Blue Ridge province will be referred to as the mountainous east to more clearly distinguish this region regarding orographic considerations.

### 1.7 Application of This Report

This report represents the current understanding of the Hydrometeorological Branch, NWS for the level of PMP and TVA precipitation and antecedent conditions in the Tennessee Valley for drainages  $\leq 3,000$  mi<sup>2</sup>. Included in these estimates

is a procedure for determining the areal distribution used to derive drainage-average values, as well as a procedure for modification of this distribution in orographic regions, and consideration of precipitation occurring over concurrent drainages. As such, these results represent the latest concepts in PMP determination for this region.

It is our recommendation that the procedures presented here be applied according to the respective regions within the Tennessee Valley, and take preference to PMP estimates determined from any other existing PMP study (vis., HMR No. 41, 45, 51 and 52) that covers this region. Numerous checks were made in nonorographic regions between estimates from this study and those from HMR No. 51 and 52. Differences were small and can be expected between results from a limited region and one that provides results for a large region.

In the eastern TVA region shown in figure 1 (coincident with the stippled designation in HMR No. 51), the methods presented in this report are pioneering efforts to consider orographic effects on a generalized scale in the Appalachian Mountains. These methods draw on procedures developed in NWS HYDRO 39 (Miller et al. 1984b), NWS HYDRO 41 (Fenn 1985), and HMR No. 55 (Miller et al. 1984a).

## **2. SUMMER PMP AND TVA PRECIPITATION FOR SMALL BASINS (<100 mi<sup>2</sup>)**

### **2.1 Development of PMP Storm Type**

#### **2.1.1 Introduction**

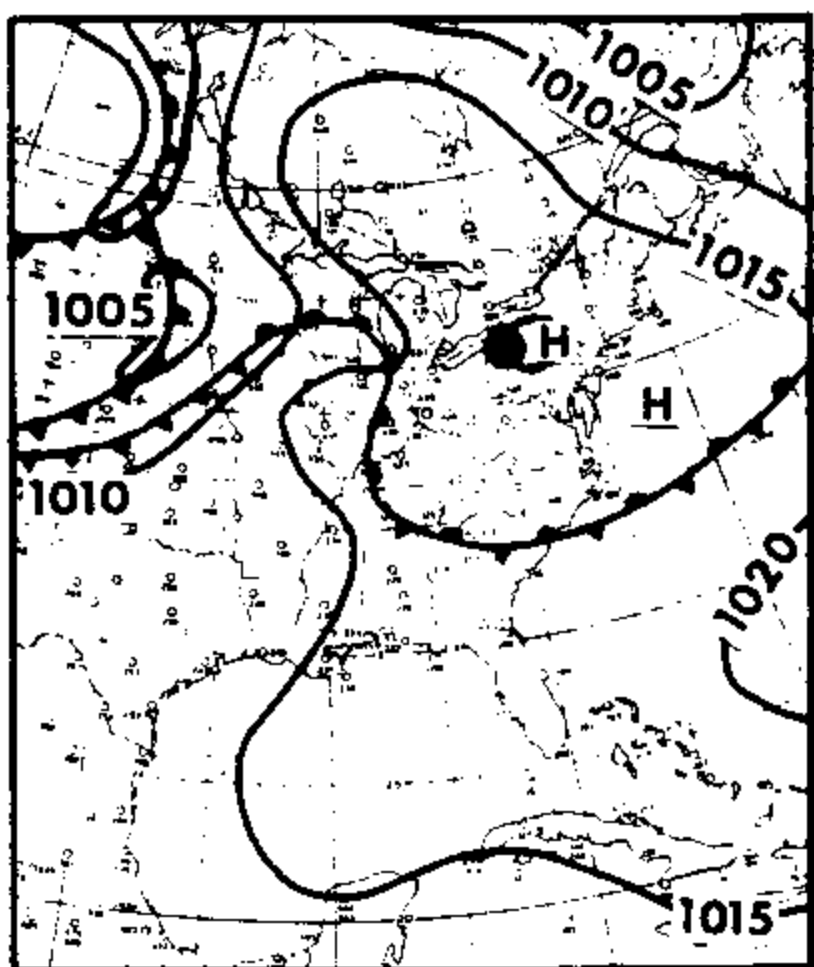
A first step in determining PMP for the Tennessee basin is to establish the type of storm which will produce the rains of PMP magnitude over the basin. The PMP storm for small areas is thunderstorm related, but the storm type differs in important ways from a "typical" thunderstorm situation.

The typical summer thunderstorm generally lasts less than 1 hr--not so with the PMP-type storm which may extend beyond 6 hr. The typical summer thunderstorm is quite restricted in area. In the PMP-type thunderstorm, larger areas may be involved with more thunderstorm activity. The typical summer thunderstorm occurs in the afternoon or evening in the Tennessee River Valley. The PMP-type thunderstorm often occurs during the nighttime hours, but can occur at any time.

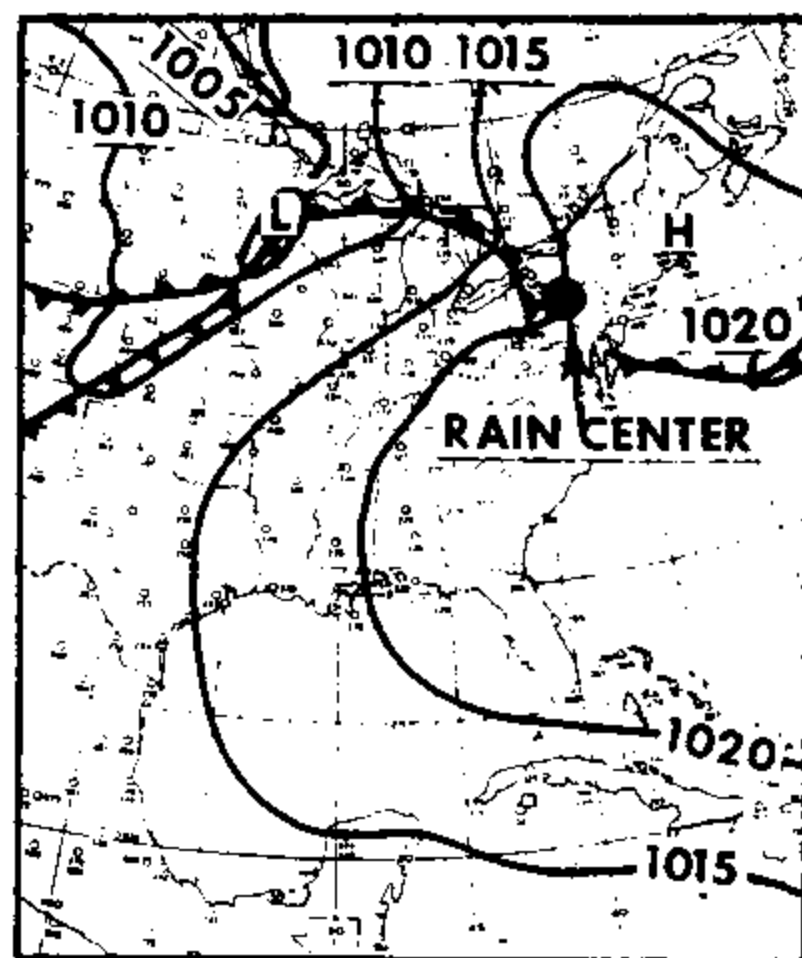
Only a very few storms have yet been observed anywhere in the United States that clearly resemble the PMP type. The best example resembling the PMP storm type for small areas that could occur over the Tennessee River basin is the Smethport, PA storm of July 17-18, 1942. Surface weather maps for this storm are shown in figure 2. Characteristics of this outstanding storm are important to establishing the PMP storm type for the Tennessee River watershed. Additional insight into the probable characteristics of the PMP storm comes from examination of other intense short-duration storms and some major large-area long-duration storms, and from the climatology of thunderstorms, including their diurnal and other characteristics.

#### **2.1.2 Intense Rains in and Near the Tennessee River Watershed**

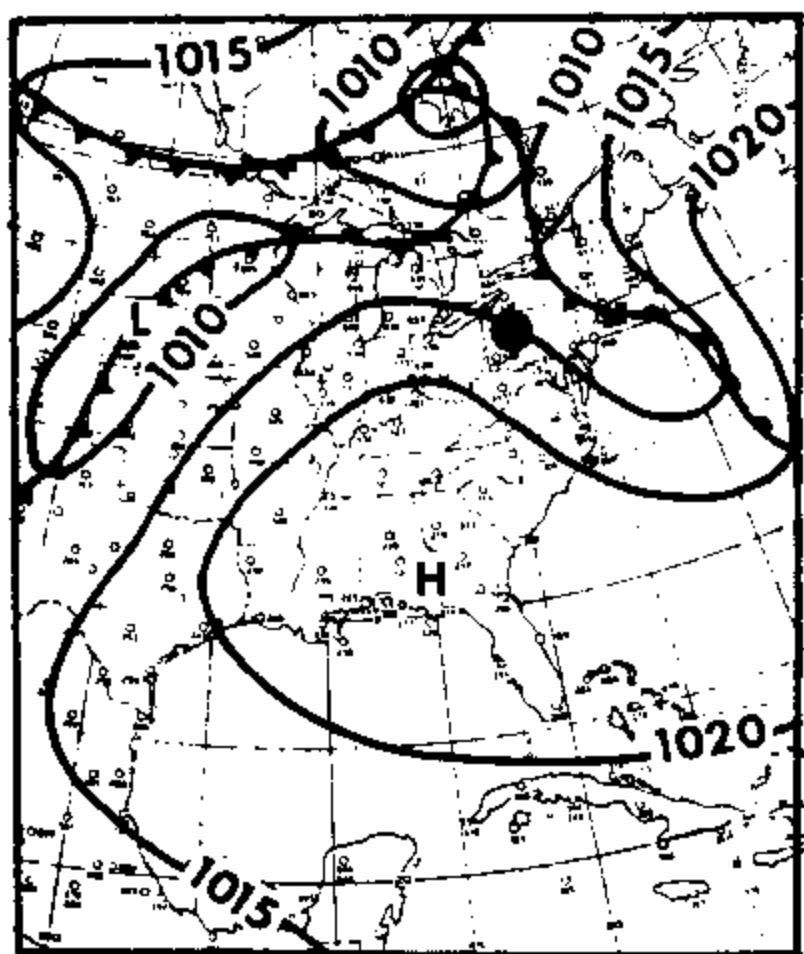
The dates, location and other information regarding intense rains in or near the Tennessee River watershed are shown in table 1. The basic information on these storms was provided by the TVA (1924-1982). Regularly reporting rainfall stations rarely catch such outstanding rains. The TVA has long recognized that the average spacing of rain gages fails to sample most extreme summer storms.



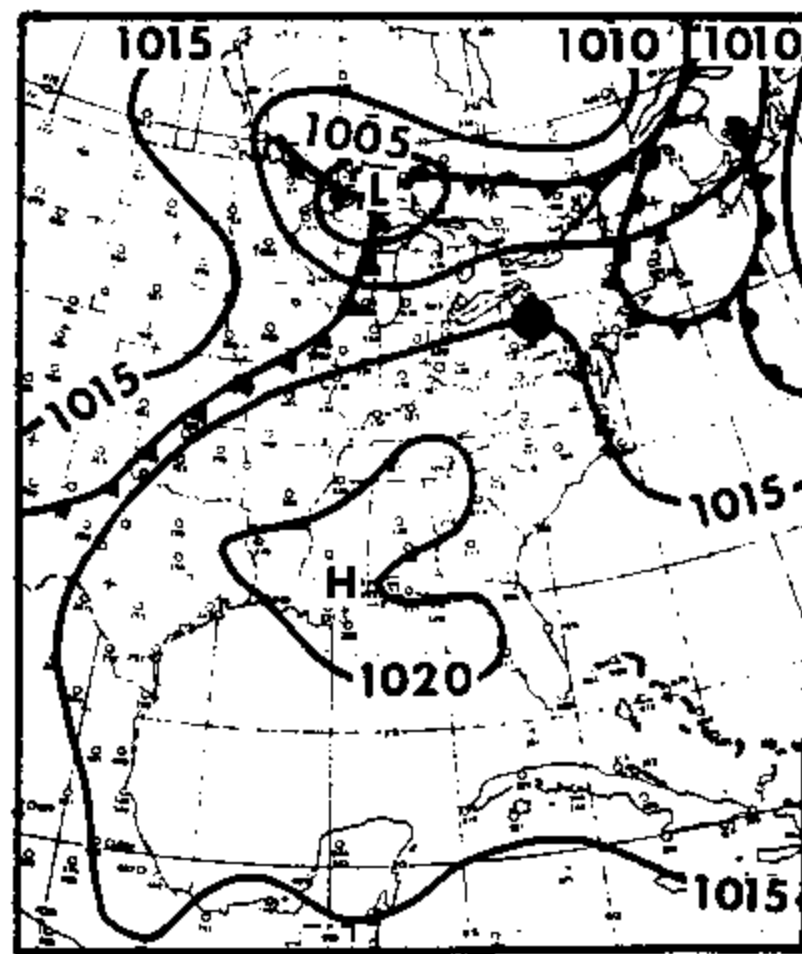
July 16, 1942 Sea Level 1230GMT



July 17, 1942 Sea Level 1230GMT



July 18, 1942 Sea Level 1230GMT



July 19, 1942 Sea Level 1230GMT

Figure 2.—Surface weather maps for the July 16-19, 1942 storm at Smethport, PA.

**Table 1. Intense rainfalls from small area storms in or near the Tennessee River watershed**

Date	Approximate Lat. (N)	Locations* Long (W)	Index No.	Durations (hr.)	Area (sq. mi.)	Depth (in.)
June 13, 1924	36°18'	82°16'	0	3.5	Point	14.4
June 2, 1937	36°16'	85°46'	1	0.3-0.4	0.35	5.5
June 3, 1937	35°49'	82°30'	2	1.5	4	6.2
June 3, 1937	36°02'	83°56'	2	0.5	4	1.8
July 30, 1937	36°15'	83°05'	3	2	4.3	5
May 22, 1938	35°57'	85°02'	4	2	Point	11
June 18, 1938	35°27'	86°48'	5	3	30	9
July 7, 1938	35°05'	82°50'	6	1	4	6
July 8, 1938	35°14'	86°06'	7	0.75	Point	8.3
August 4, 1938	35°46'	83°26'	7a	3-4	Point	12.3
June 9, 1939	37°12'	80°48'	8	4	25	10
April 20, 1940	35°47'	88°22'	9	1	6	1.73
June 7, 1940	35°14'	88°24'	10	1	0.125	3.5
June 18, 1940	36°27'	84°05'	11	0.75	7	4.5
July 8, 1940	36°22'	83°03'	12	1	1.5	4.5
July 11, 1941	35°11'	86°47'	13	2	15	6
July 13, 1941	36°10'	82°24'	14	2	7.45	4
August 6, 1943	35°05'	85°04'	15	0.75	Point	3
May 15, 1946	35°08'	85°17'	16	1.5	Point	6
May 15, 1946	35°08'	85°17'	17	3	6.21	6.7
June 28, 1947	36°04'	82°50'	18	3.5	Point	5.4
July 28, 1947	35°45'	83°15'	19	3	Point	5.8
June 4, 1949	35°55'	85°28'	20	2	Point	9.5
July 16, 1949	36°14'	83°20'	21	1.75	Point	4.5
July 19, 1949	35°22'	83°13'	22	1	0.98	5.5
July 25, 1951	35°06'	84°39'	23	2	8	5.6
July 28, 1951	35°38'	83°00'	24	0.75	Point	6.0
July 28, 1951	36°04'	82°50'	25	0.5	Point	3.2
Sept. 1, 1951	35°33'	83°10'	26	1	Point	6.5
Sept. 1, 1951	35°43'	83°31'	27	1	Point	6.5±
June 5, 1952	34°58'	83°55'	28	1	2	4.2
June 13, 1952	35°41'	85°48'	29	3	Point	10.5
June 13, 1952	35°09'	84°11'	30	6	Point	7.8
July 6, 1953	36°54'	81°19'	31	2	5	4
July 18, 1953	35°02'	85°12'	32	2	Point	5.2
June 13, 1954	36°36'	82°11'	33	0.92	50.2	3.0
Aug. 8-9, 1954	35°07'	85°36'	34	3±	30±	10±
March 21, 1955	35°06'	87°26'	35	0.2	Point	0.8
June 21, 1956	37°06'	83°43'	36	3	Point	11.7
Sept. 6, 1957	35°46'	82°25'	37	2	3.56	5.5

**Table 1. Intense rainfalls from small area storms in or near the Tennessee River watershed (continued)**

Date	Approximate Lat. (N)	Locations* Long (W)	Index No.	Durations (hr.)	Area (sq. mi.)	Depth (in.)
June 30, 1956	35°36'	83°01'	38	1	Point	10-12
Nov. 18-19, 1957	35°42'	81°55'	39	2.0	Point	10.3
July 23, 1958	35°52'	84°31'	40	0.6	Point	2.0
July 24, 1958	35°51'	84°41'	41	2.5	Point	2.8
August 12, 1958	35°48'	82°40'	42	1.5	Point	3.2
June 9, 1959	35°38'	88°11'	43	1	10.6	2.1
Aug. 25, 1959	35°02'	85°12'	44	1	Point	2.4
June 16, 1960	35°32'	87°01'	45	3	Point	12.8
July 26, 1960	34°33'	84°04'	46	3	Point	12.5
August 10, 1960	35°51'	84°41'	47	1.5	11.7	3.4
August 10, 1960	35°56'	84°19'	48	3.3	Point	9
June 12, 1961	36°02'	82°06'	49	2.5	3.49	8.5
July 23, 1963	34°27'	86°56'	50	1.5	4	7
April 28, 1964	35°11'	84°49'	51	1	1	4
July 24, 1965	36°36'	83°43'	52	4	Point	11
July 24, 1965	36°14'	84°17'	53	3	10	12
April 26, 1966	35°10'	88°12'	54	1.33	2	5.2
August 9, 1966	35°13'	88°19'	55	1.5	Point	5.2
December 8, 1966	35°20'	86°55'	56	5	2	3.3
May 12, 1967	35°40'	87°10'	57	1	Point	3.3
June 3, 1967	35°12'	82°15'	58	6	Point	5.5
August 4, 1968	36°16'	82°10'	59	0.50	Point	2.2
Sept. 16, 1968	34°35'	87°50'	60	5	Point	11.1
April 25, 1970	35°51'	84°40'	61	1.5	Point	3.0
June 15, 1970	35°32'	88°15'	62	0.75	Point	1.8
August 3, 1971	36°58'	81°55'	63	1	Point	1.8
August 5, 1971	36°40'	81°45'	64	0.58	Point	1.9
August 2, 1972	36°35'	82°30'	65	1	Point	3.5
April 26, 1973	35°02'	85°10'	66	2	Point	5.5
May 18, 1974	36°50'	81°45'	67	0.75	Point	3.2
May 30, 1974	35°40'	83°45'	68	5	Point	6.6
June 22, 1974	36°22'	82°03'	69	1.5	Point	2.2
October 1, 1977	36°38'	82°30'	70	4	Point	3.3
Sept. 10, 1978	36°35'	83°10'	71	0.75	Point	4.0
May 3, 1979	35°40'	88°38'	72	4	Point	4.6
June 22, 1979	36°22'	82°03'	73	3	Point	2.6
July 21, 1979	34°55'	86°42'	74	2	Point	4.3
August 29, 1981	34°30'	86°12'	75	1	Point	6.3
July 30-31, 1982	36°00'	83°58'	76	4	Point	8.2
August 17, 1982	35°20'	85°17'	77	3	Point	15.5

Its engineers have made many field investigations immediately following the occurrence of severe storms to obtain "bucket" rainfall measurements (TVA 1961), and there is a fairly complete record of such storms from this region dating back to 1924 (table 1).

The meteorology of the intense storms of table 1 was investigated by studying the surface, and where available, upper-air weather charts. The weather maps of these storms showed no consistent pattern of synoptic conditions in relation to causes of the heavy rains. About half of the storms involved surface fronts separating contrasting air masses. Some showed strong low-level inflow of moisture (e.g., May 15, 1946 and July 19, 1949), while others had weak moisture inflow (e.g., June 4, 1949).

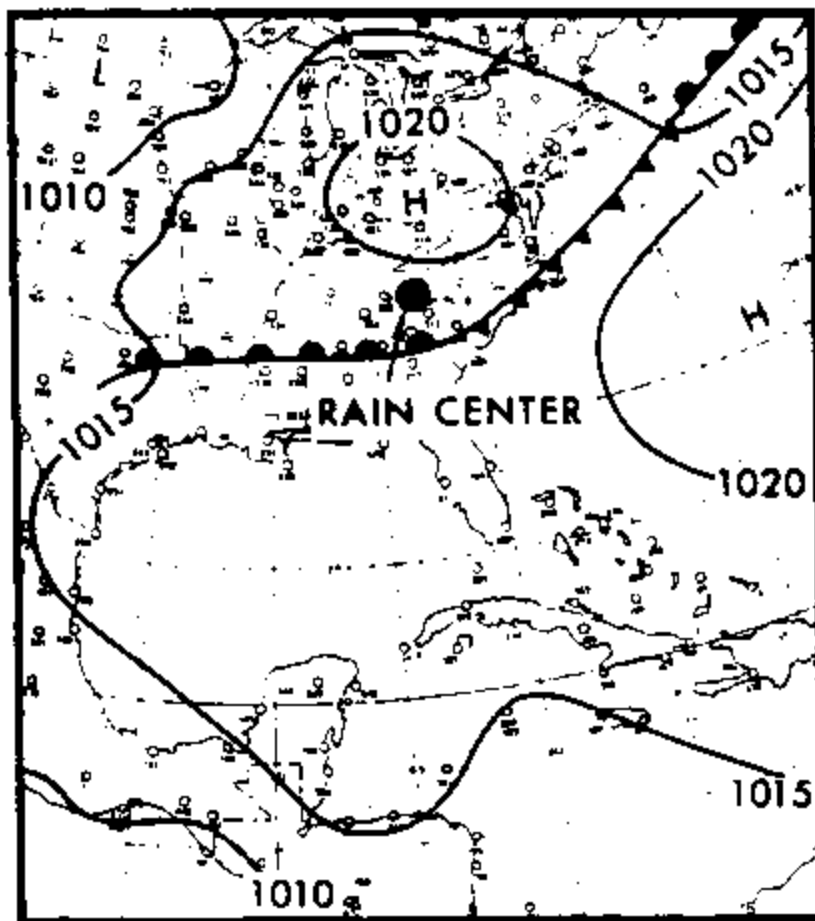
Figures 3 and 4 show weather maps for two of the more important TVA storms. The June 30, 1956 storm (fig. 3) reportedly produced 10 to 12 in. of rain (table 1) in about 1 hr, based on runoff computations. The precipitation fell mostly between noon and 1 p.m. on June 30. A weak warm front at the surface and a minor trough of low pressure at 500 mb seem to have been contributing factors. A similar intense storm involving more surface inflow was that of June 21, 1956, near Manchester, KY (fig. 4). This storm also produced nearly 12 in. of rain in 3 hr (table 1).

Regardless of the weather factors operating, a common feature of most extreme rains in and near the Tennessee River watershed, as with similar rains elsewhere, is the degree of organization and geographic "fixing" of convective activity. Huff and Changnon (1961) reported such a feature in an investigation of severe rainstorms in Illinois. Huff (1967) discussed two additional Illinois storms, emphasizing the importance of a succession of convective cells reaching their greatest intensity over the same general area. These Illinois storms, in lasting about 4 hr, come a little closer to representing the PMP storm type for a maximum 24-hr rain in the Tennessee Valley than did most of the TVA storms which had shorter durations. Maddox (1981) also discussed the effects of convective activity on a mesoscale storm over the central Mississippi Valley. Both authors hypothesized that the strong changes in temperature, wind, and pressure-surface heights in and around such storms were the result of a deep layer of mid-tropospheric convective warming.

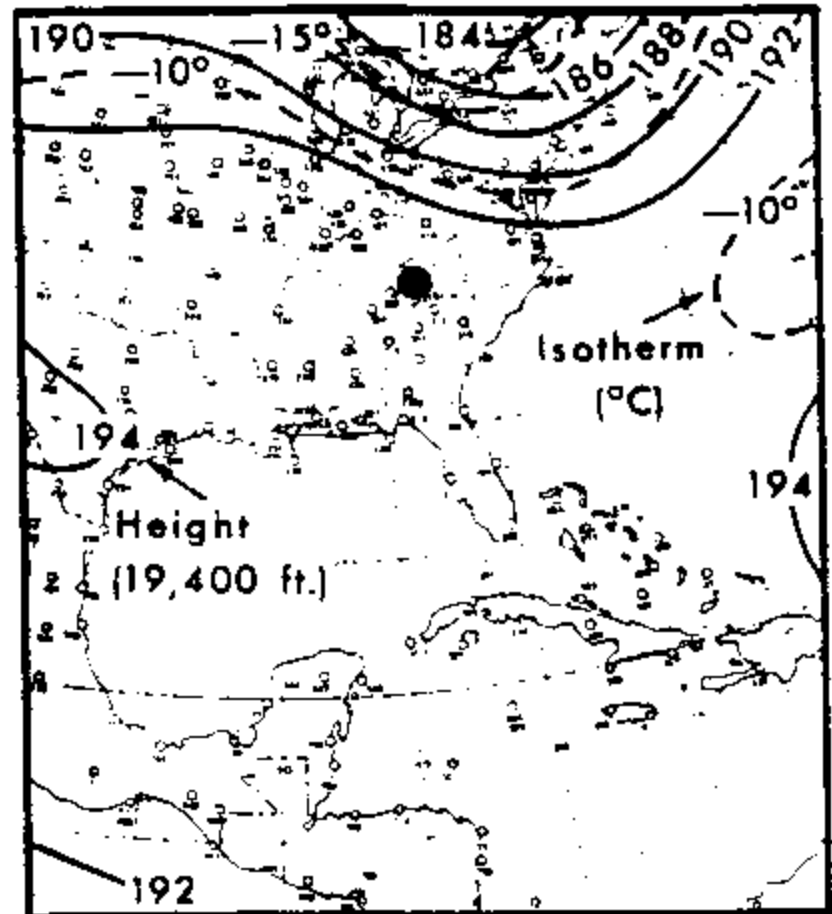
One does not always find fronts or other easily identifiable causes of intense rains whether in the Tennessee River watershed or elsewhere. A discussion (Woodley 1967) of a wintertime occurrence of such organized convection within a warm-air mass concluded that "...convective organization is the difference between little rain in one region and 10 in. in another." Only slight triggering mechanisms are necessary to release the air's convective instability. Such triggering disturbances, when they exist aloft, are not always detectable in synoptic scale upper-air analyses because of the sparse upper-air network.

### 2.1.3 Orographic Considerations

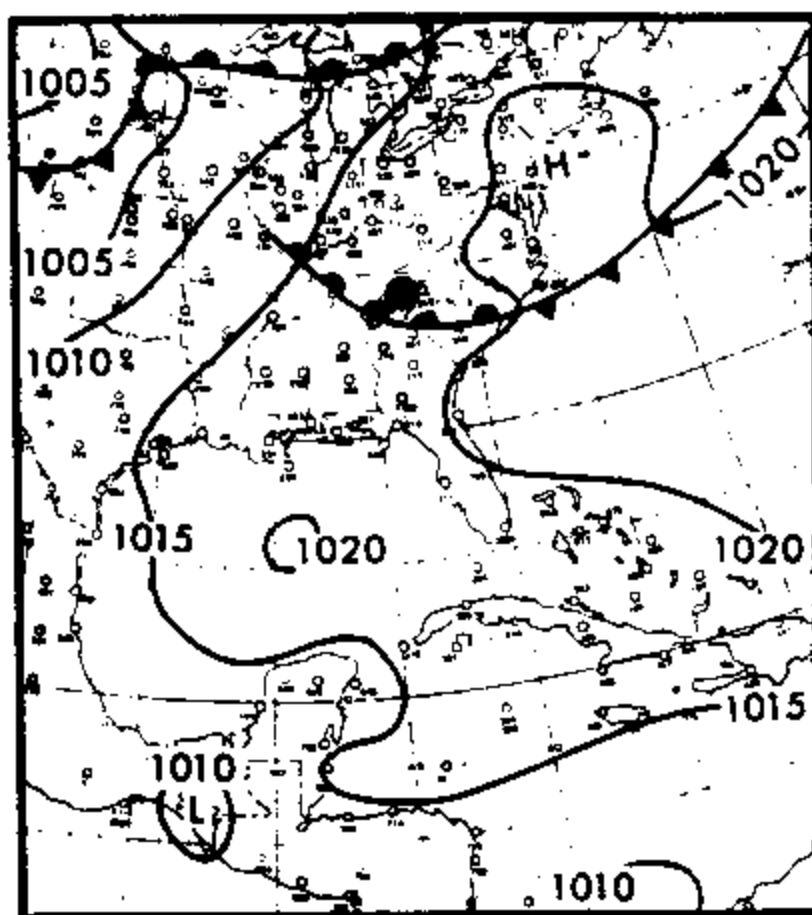
Approximate terrain elevations were determined for most of the storms in table 1. Elevations ranged from 700 ft to over 4,000 ft. A unique rainfall-elevation relation was not evident. This lack of relation supports a procedure that does not overemphasize the role of orography in short-duration rains. In addition to no correlation with orography, there was only a very slight geographical pattern discernible in the data of table 1.



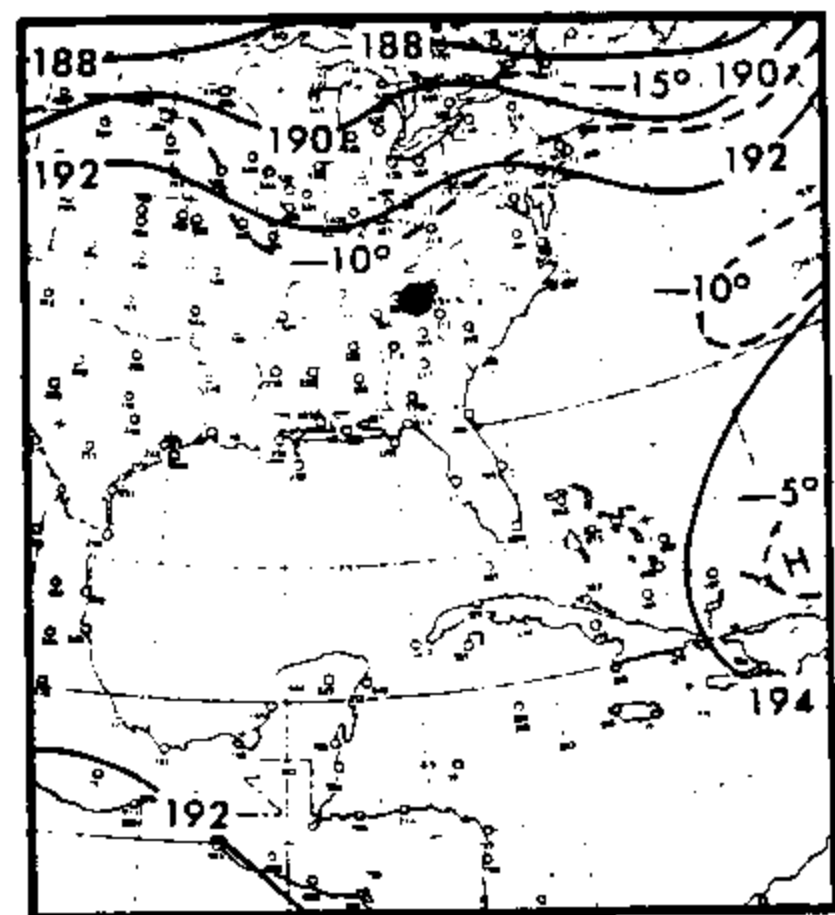
June 29, 1956 Sea Level 1230GMT



June 29, 1956 500 MB 1500GMT

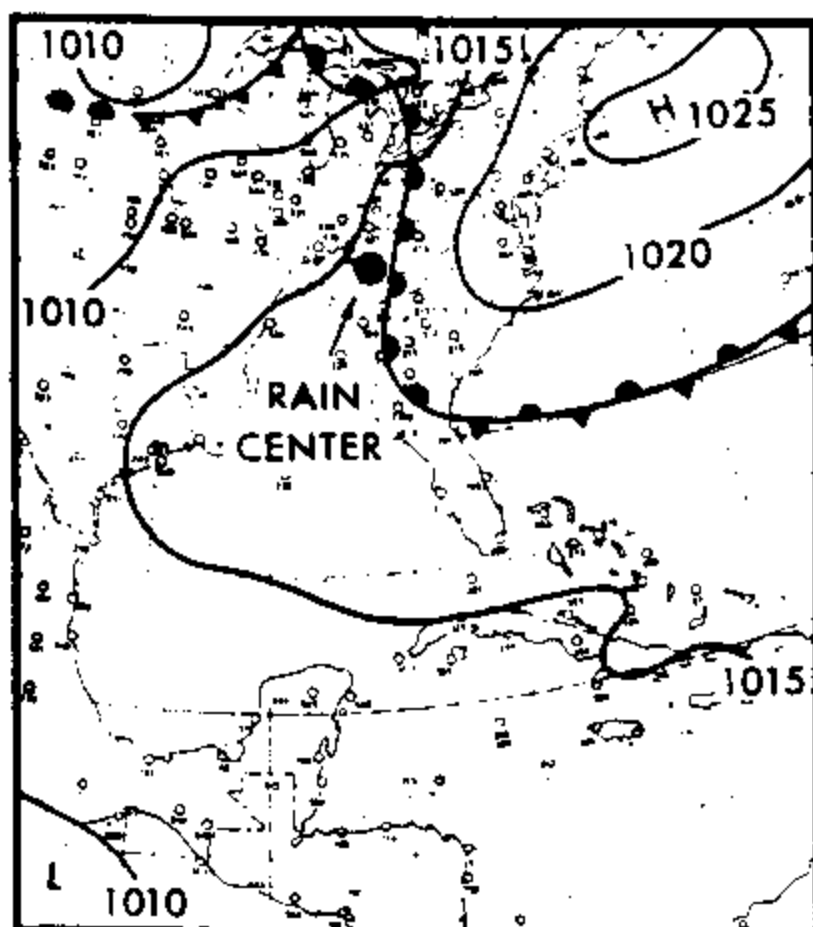


June 30, 1956 Sea Level 1230GMT

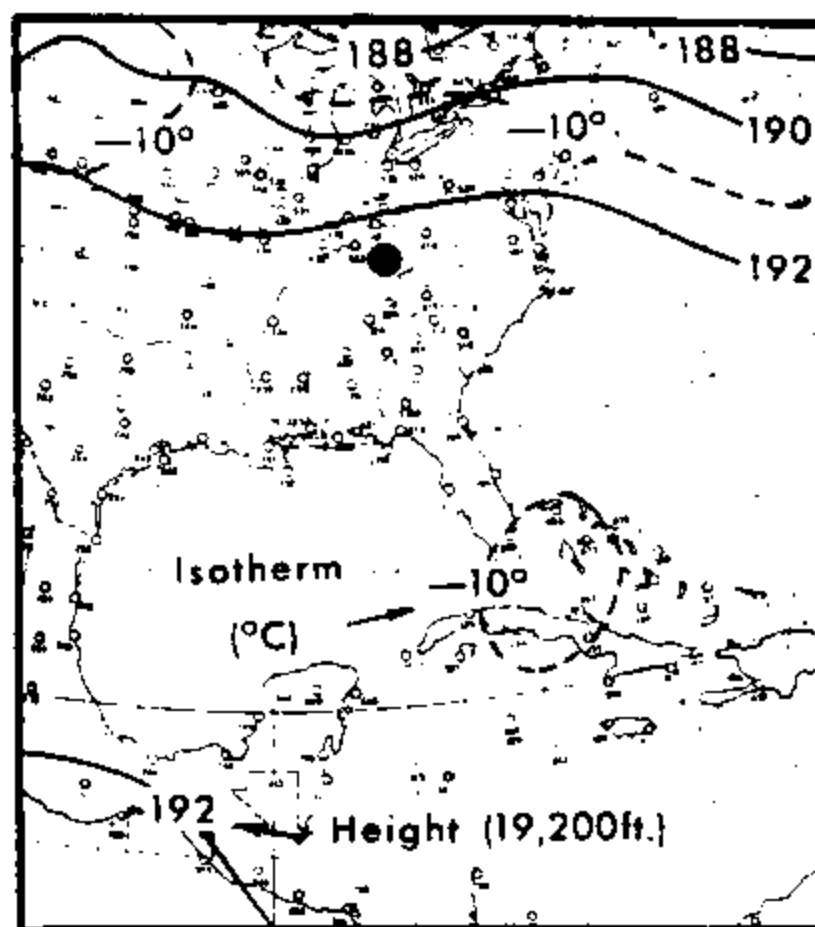


June 30, 1956 500 MB 1500GMT

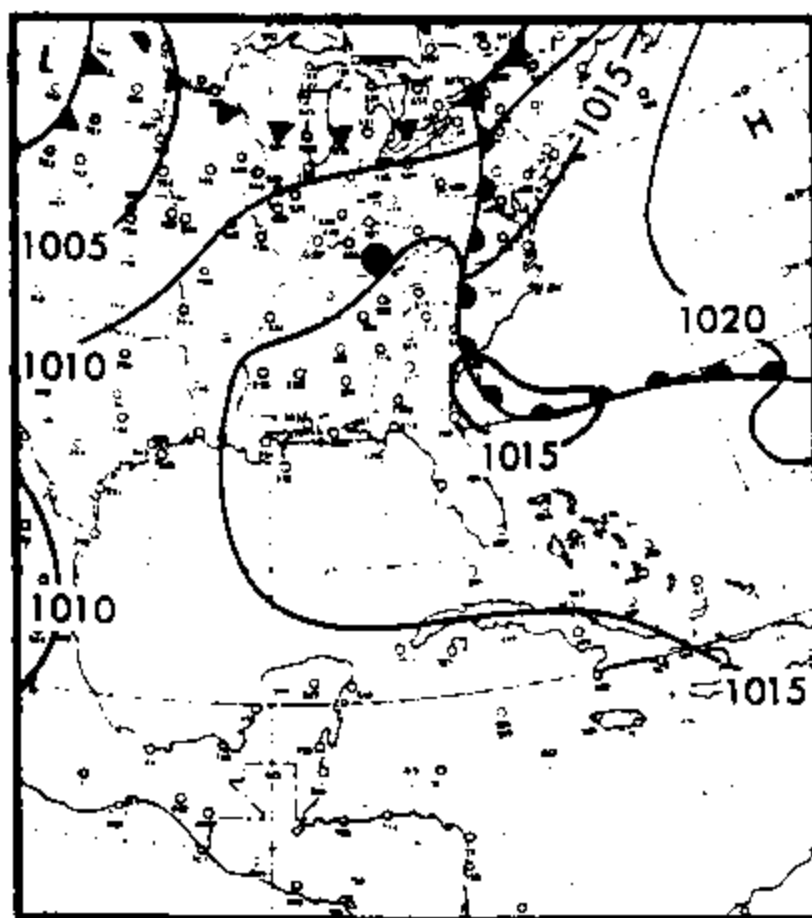
Figure 3.--Surface and upper-air weather maps for June 30, 1956 storm in Cove Creek Basin, NC.



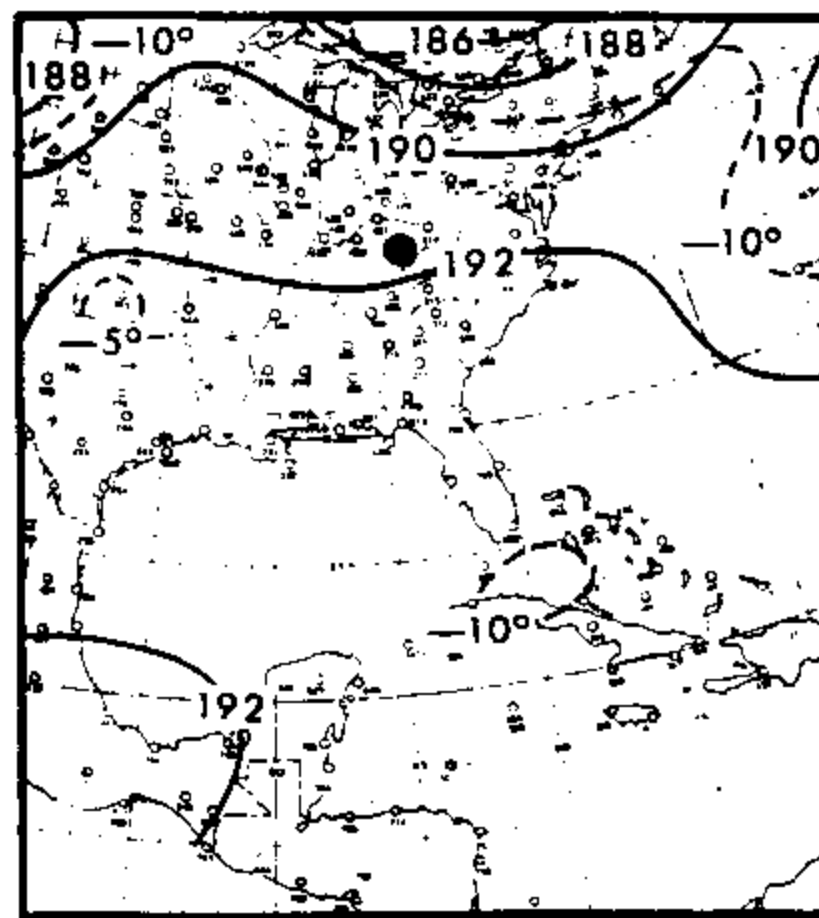
June 20, 1956 Sea Level 1230GMT



June 20, 1956 500 MB 1500GMT



June 21, 1956 Sea Level 1230GMT



June 21, 1956 500 MB 1500GMT

Figure 4.--Surface and upper-air weather maps for June 21, 1956 for the storm near Manchester, KY.

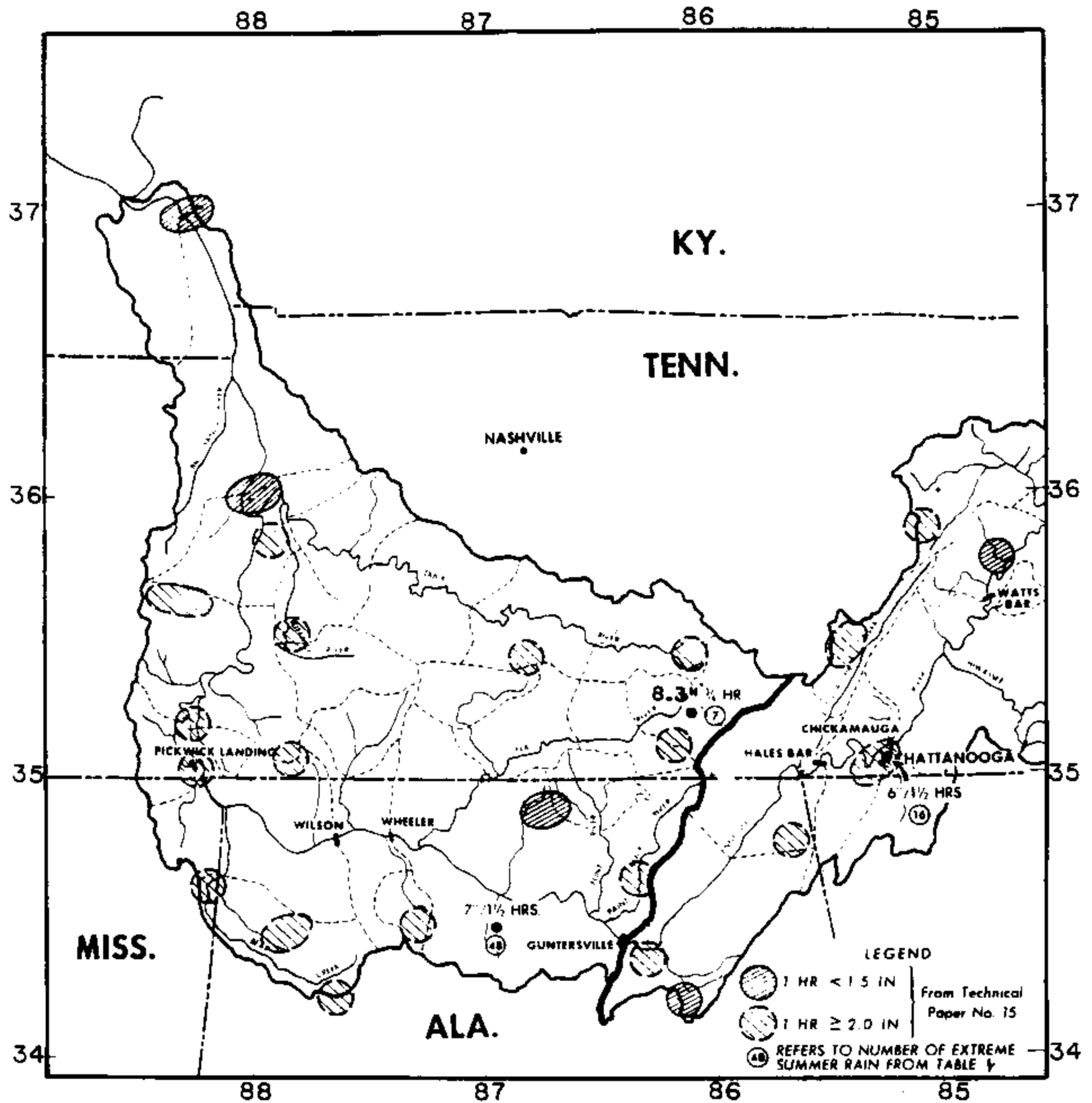


Figure 5.--Maximum observed 1-hr rains over western Tennessee River watershed (note overlap of eastern region shown in fig. 6).

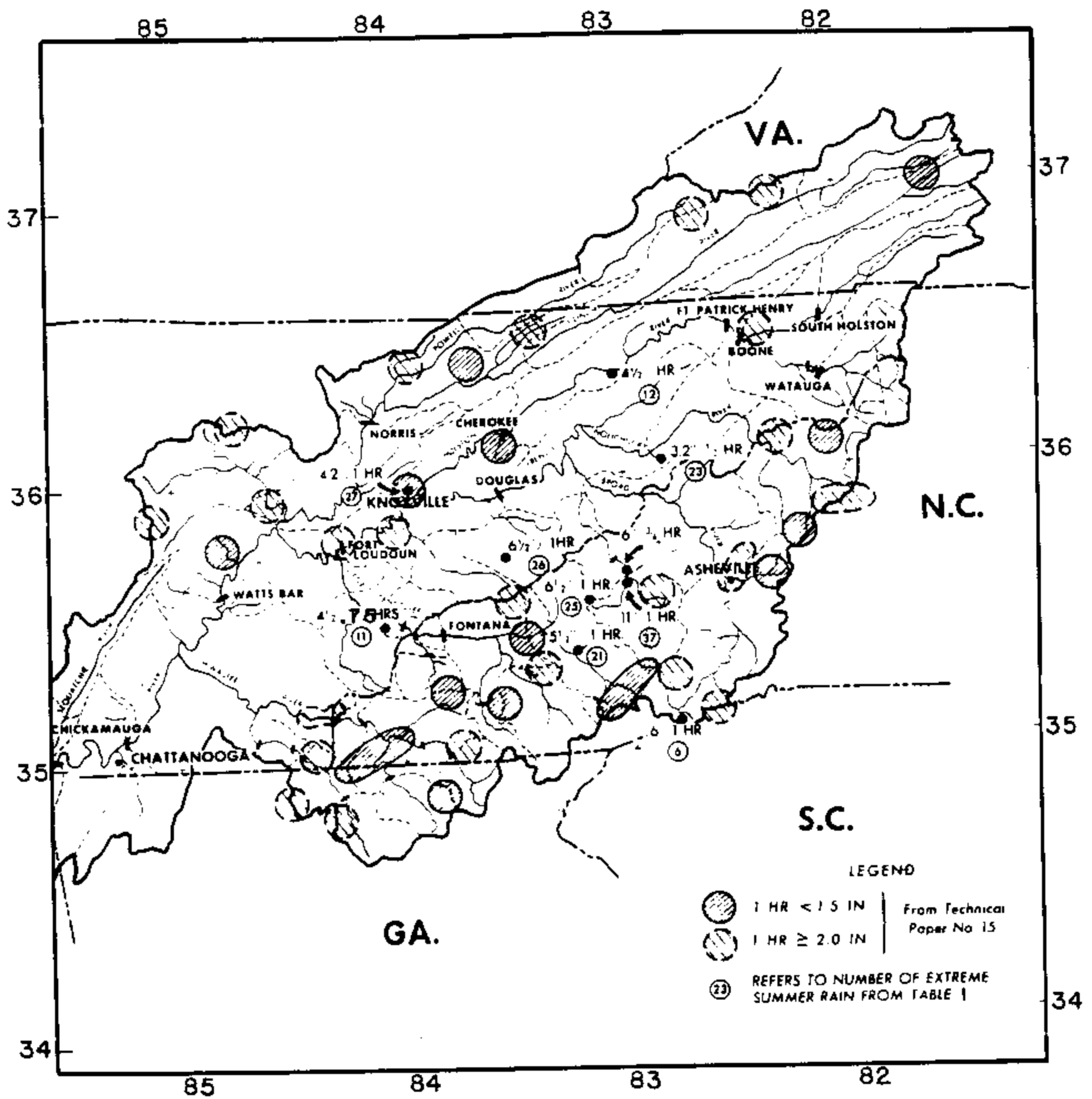


Figure 6.--Maximum observed 1-hr rains over eastern Tennessee River watershed.

Some of the more important values from table 1 were plotted in figures 5 and 6. Also shown on these figures are areas of maximum 1-hr rains obtained from Technical Paper No. 15 (U.S. Weather Bureau 1956). In order to reveal any possible regional differences the amounts are categorized into those exceeding 2 in. and those less than 1.5 in. in a 1-hr duration. There is no clear-cut regional preference. There is some slight tendency of rainfall areas with greater than 2 in. occurring along the southern boundary and in the mountainous east than in other regions. These factors and examination of maximum 1-hr amounts in major storms suggest that a very slight gradient in short-duration rainfall exists with somewhat greater values in the rougher terrain. In figures 5 and 6, rainfalls from TP 15 obtained from single stations are shown by circular symbols, while rainfall events from groups of stations are indicated by elliptical symbols.

Maximum 24-hr rains obtained from Technical Paper No. 16 (Jennings 1952) over the eastern, more mountainous portion of the Tennessee River watershed were plotted and analyzed for two rainfall categories; 24-hr rains in excess of 8 in., and those less than 4 in. On this basis, generalized areas of greatest or least orographic potential were outlined as shown in figure 7. The effects of upslope and broadscale sheltering are clearly indicated. These effects are discussed more thoroughly later in this chapter.

#### **2.1.4 Intense Short-Duration Rains Throughout the Eastern United States**

Intense small-area short-duration storms were extracted from over 600 storm studies prepared in "Storm Rainfall for the United States" (U.S. Army Corps of Engineers 1945-). The pertinent storms for assessing intense small-area rains were all cases of 6-hr 10-mi<sup>2</sup> rainfall of 10 in. or more (table 2). Particular attention was given to those cases exceeding 15 in. in 6 hr, and to those rainfall amounts less than 15 in. that would later be greatly maximized due to a larger moisture adjustment. In addition, all cases listed in "Storm Rainfall" with durations shorter than 6 hr were summarized. The locations of some of the more important maximum values of table 2 are shown in figure 8. Both observed and moisture-maximized values are shown.

Again, as with the intense storms listed in table 1, no single clearly defined storm type emerges from the examination of the meteorological descriptions associated with these rainfalls. Suffice it to say the Smethport, PA storm of July 17-18, 1942, with its characteristics of lasting through the night and being part of a larger area of thunderstorms, while concentrating the rain over a fixed area, single it out as most clearly depicting the PMP storm type for the TVA region.

#### **2.1.5 Clues From Larger Area Storms**

Since storms like the Smethport storm are such a rarity, we are forced to turn to storms producing less phenomenal rainfall totals in order to further characterize the PMP storm type. One criterion used for selecting summer (or summer-type) storms which produced large volumes of rainfall in or near the Tennessee River watershed was the number of stations which simultaneously recorded maximum 24-hr rains. Weather Bureau Technical Paper No. 16 (Jennings 1952) together with a survey of data more recently available in a computer compatible form (Peck et al. 1977) provides a convenient summary. From this survey involving several hundred stations, nine significant storms were identified. These are listed in table 3, which gives the storm date and the

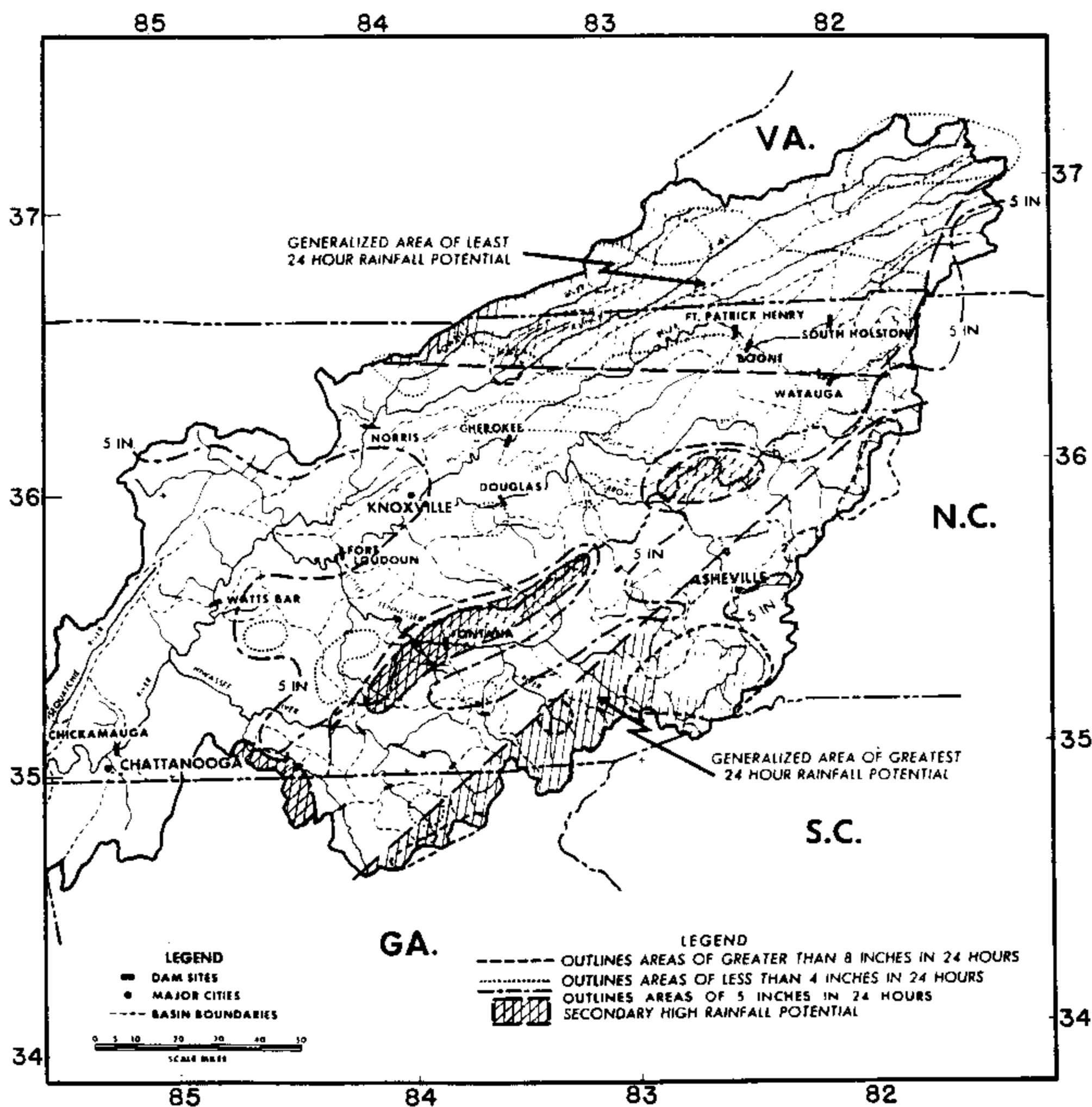


Figure 7.—Areas of greatest and least 24-hr rainfall potential, based on station rainfall data.

**Table 2.--United States rainfall occurrences equaling or exceeding 10 in. in 6 hr\***

Date	Observed amount (in.) 6 hr 10 mi <sup>2</sup>		Moisture maximization (percent)
June 13-17, 1886	11.5	Alexandria, LA	16
June 23-27, 1891	10.4	Larabee, IA	28
June 4-7, 1896	12.0	Greeley, NE	55
July 26-29, 1897	13.0	Jewell, MD	41
June 12-13, 1907	6.2 (3 hr)	Fort Meade, SD	28
July 18-23, 1909	10.5	Ironwood, MI	34
July 18-23, 1909	10.5	Beaulieu, MN	34
Aug. 28-31, 1911	14.9	St. George, GA	21
Aug. 31-Sept. 1, 1914	12.6	Cooper, MI	55
Aug. 1-3, 1915	12.9	St. Petersburg, FL	16
Sept. 28-30, 1915	10.1	Franklinton, LA	16
July 5-10, 1916	15.9	Bonifay, FL	10
June 2-6, 1921	10.4	Pueblo, CO	51**
June 17-21, 1921	10.5	Springbrook, MT	31**
Sept. 8-10, 1921	22.4	Thrall (Taylor) TX	5
July 9-12, 1922	10.8	Grant City, MO	34
Oct. 4-11, 1924	13.6	New Smyrna, FL	21
Sept. 11-16, 1926	13.4	Neosho Falls, KS	34
Sept. 17-19, 1926	15.1	Boyden, IA	34
April 12-16, 1927	13.8	Jeff.-Plaq.Drain. Dist., LA	22
March 11-16, 1929	14.0	Elba, AL	34
May 25-30, 1929	11.3	Henly, TX	10
June 20-July 2, 1932	13.3	State Fish Hatchery, TX	16
Aug. 30-Sept. 5, 1932	10.0	Fairfield, TX	10
April 3-4, 1934	17.3	Cheyenne, OK	49
May 2-7, 1935	10.6	Melville, LA	22
May 16-20, 1935	13.8	Simmesport, LA	28
May 30-31, 1935	20.6	Cherry Creek, CO	63**
June 27-July 4, 1936	14.0	Bebe, TX	0
Sept. 14-18, 1936	16.0	Broome, TX	5
May 30-31, 1938	10.0	Sharon Springs, KS	55
July 19-25, 1938	11.5	Eldorado, TX	16
Aug. 12-15, 1938	10.9	Koll, LA	10
May 25, 1939	8.2 (2 hr)	Lebanon, VA	22
June 19-20, 1939	18.8	Snyder, TX	23**
July 4-5, 1939	18.6 (3 hr)	Simpson P.O., KY	16
July 4-5, 1939	20.0	Simpson P.O., KY	16
Aug. 21, 1939	9.5 (3hr)	Baldwin, ME	5
June 3-4, 1940	13.0	Grant Township, NE	63
June 28-30, 1940	11.0	Engle, TX	5

**Table 2.--United States rainfall occurrences equaling or exceeding 10 in. in 6 hr\* (continued)**

Date	Observed amount (in.) 6 hr 10 mi <sup>2</sup>		Moisture maximization (percent)
Sept. 1, 1940	20.1	Ewan, NJ	22
Sept. 2-6, 1940	18.4	Hallett, OK	41
May 22, 1941	6.5 (3 hr)	Plainville, IL	63
Oct. 17-22, 1941	12.9	Trenton, FL	16
April 14-17, 1942	13.1	Green Acres City, FL	48
July 17-18, 1942	24.7	Smethport, PA	10
May 12-20, 1943	15.9	Near Mounds, OK	28
June 5-7, 1943	14.2	Silver Lake, TX	16
July 27-29, 1943	10.7	Devers, TX	10
Aug. 4-5, 1943	11.1	Glenville, WV	16
June 10-13, 1944	13.4	Stanton, NE	41
July 9, 1945	9.1 (4 hr)	Easton, PA	80
Aug. 26-29, 1945	10.1	Hockley, TX	16
Aug. 12-15, 1946	10.6	Cole Camp, MO	21
Sept. 26-27, 1946	15.8	San Antonio, TX	10
June 18-23, 1947	11.5	Holt, MO	16
Aug. 27-28, 1947	13.8	Wickes, AK	28
Aug. 24-27, 1947	10.9	Dallas, TX	10
June 23-24, 1948	13.2	Del Rio, TX	35**
Sept. 3-7, 1950	16.0	Yankeetown, FL	10
June 23-28, 1954	16.0	Vic Pierce, TX	30**
June 23-24, 1963	14.6	David City, NE	34
June 17, 1965	11.5	Near Lamar, CO	28
August 12-13, 1966	11.4	Greeley, NE	28
August 19-20, 1969	14.2	Tyro, VA	5
October 10-11, 1973	16.9	Enid, OK	10

\*

A few cases of storms less than 6 hr duration are included.

\*\*

Revised moisture maximization adjustments obtained from HMR No. 55 (Miller et al. 1984)

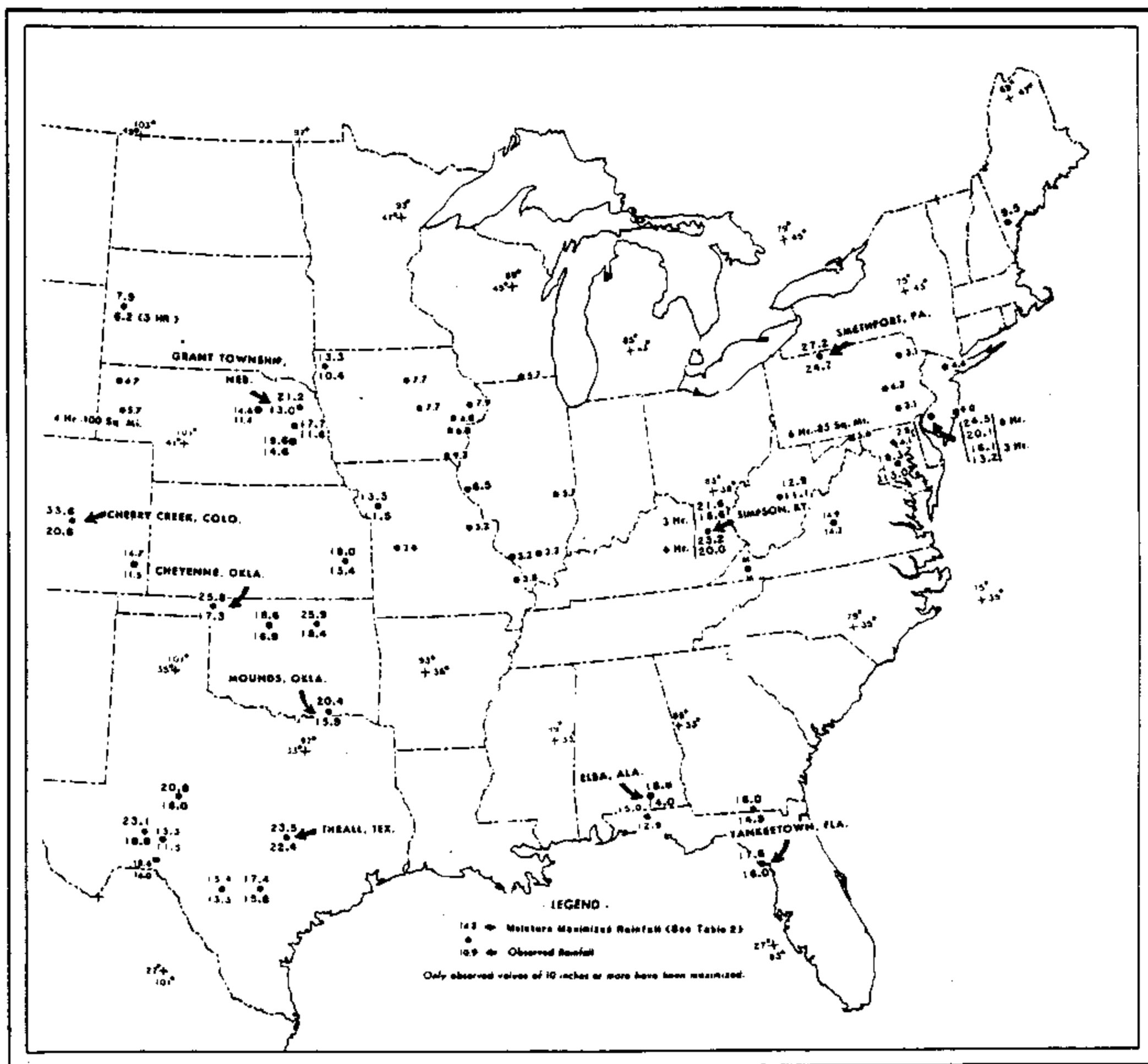
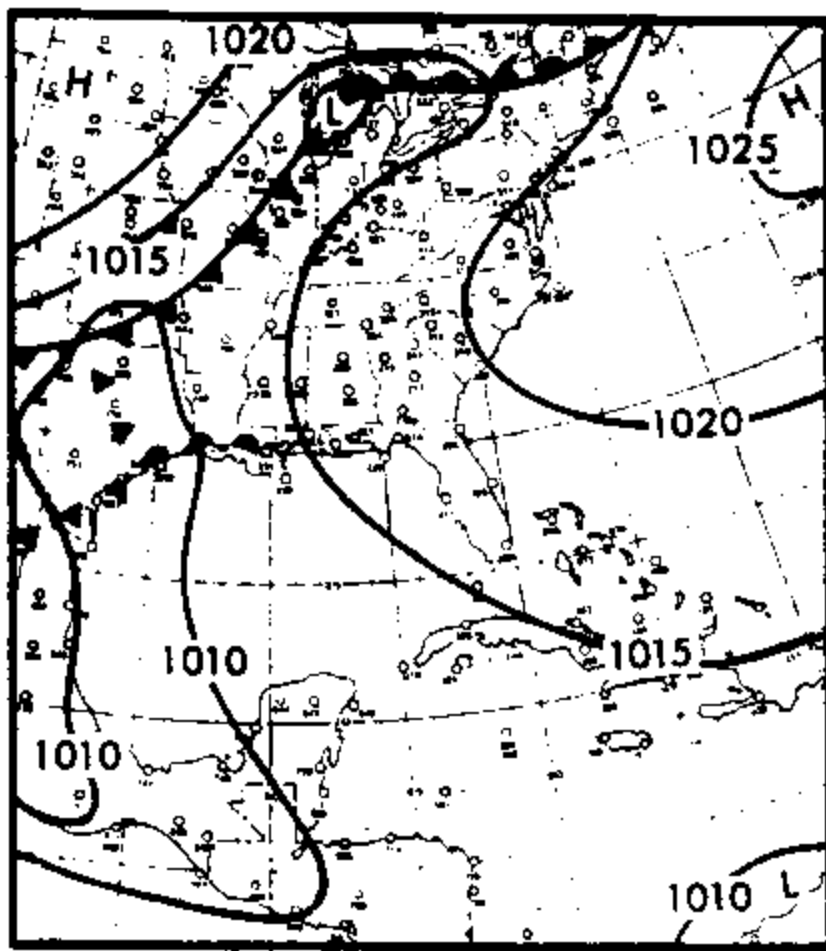


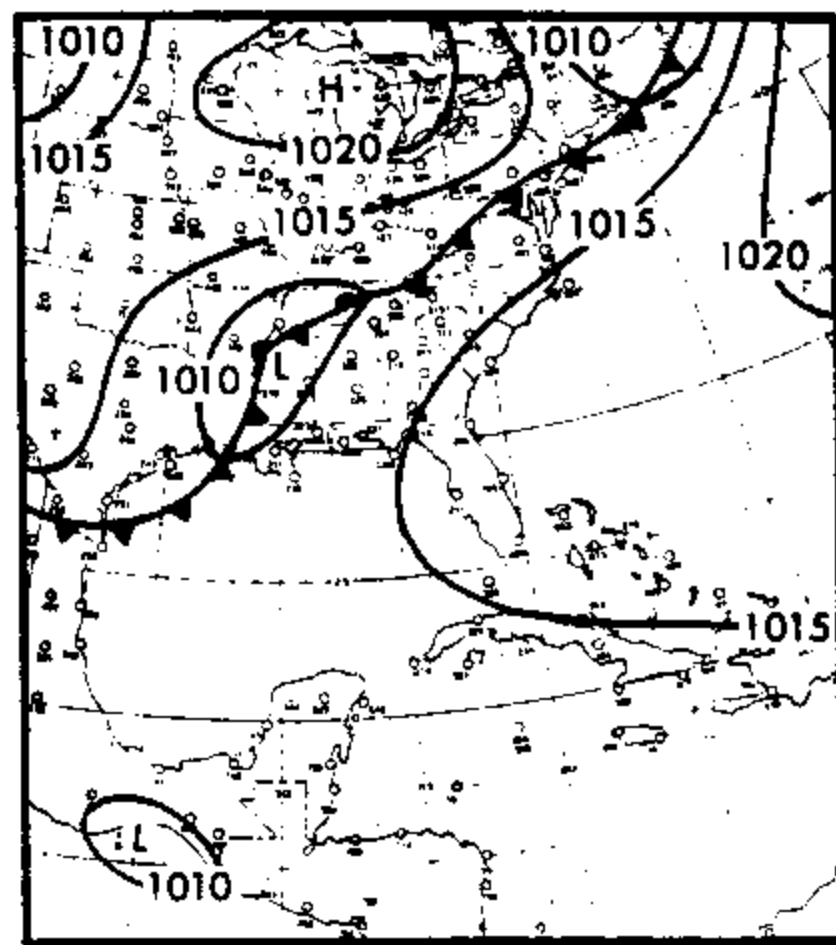
Figure 8.—Observed and moisture maximized 6-hr 10-mi<sup>2</sup> rainfall values from Storm Rainfall in the United States (U.S. Army 1945 - ).

number of stations recording their maximum 24-hr rains during this period. Weather maps for two of the storms in table 3 (September 1944 and June 1949) are shown in figures 9 and 10. Figures 9 and 10 indicate that significant cold and warm fronts are likely to be associated with the rainfall from these storms.

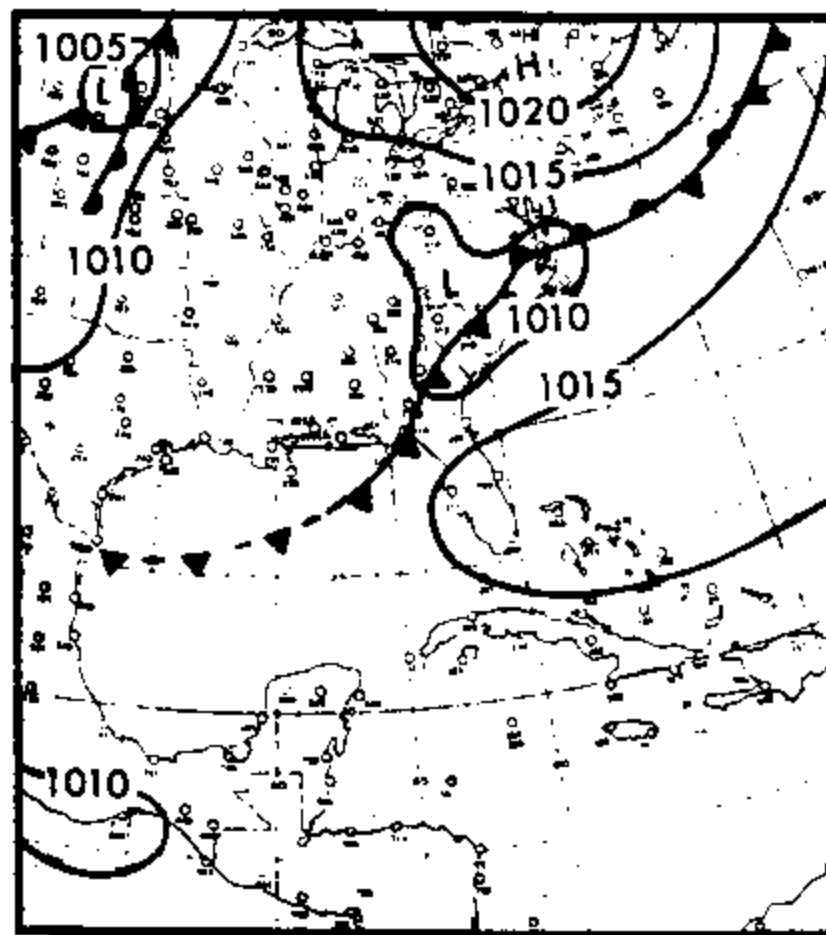
The fact that most of the above storms do not occur in the midsummer period is of interest. They are close enough to midsummer to draw upon high moisture values, yet close enough to the cooler seasons to utilize more efficient rain-enhancing mechanisms, such as the convergence associated with significant fronts, etc. Since rain-enhanced mechanisms are more frequent in the vicinity of the



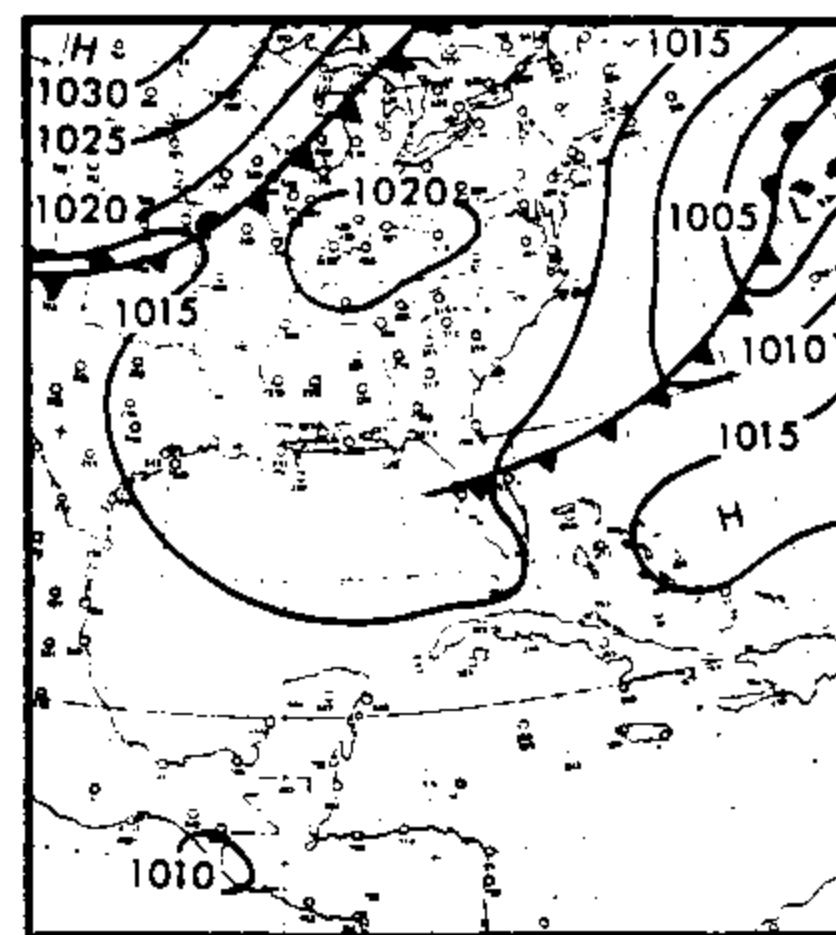
Sept. 28, 1944 Sea Level 1230 GMT



Sept. 29, 1944 Sea Level 1230 GMT

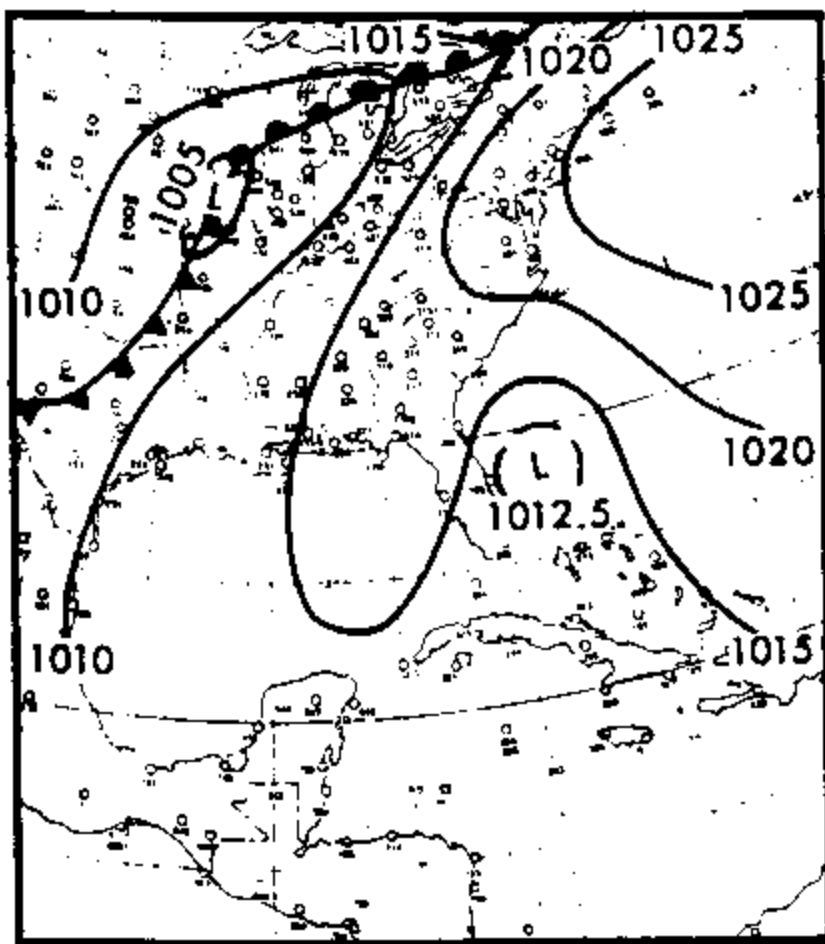


Sept. 30, 1944 Sea Level 1230 GMT

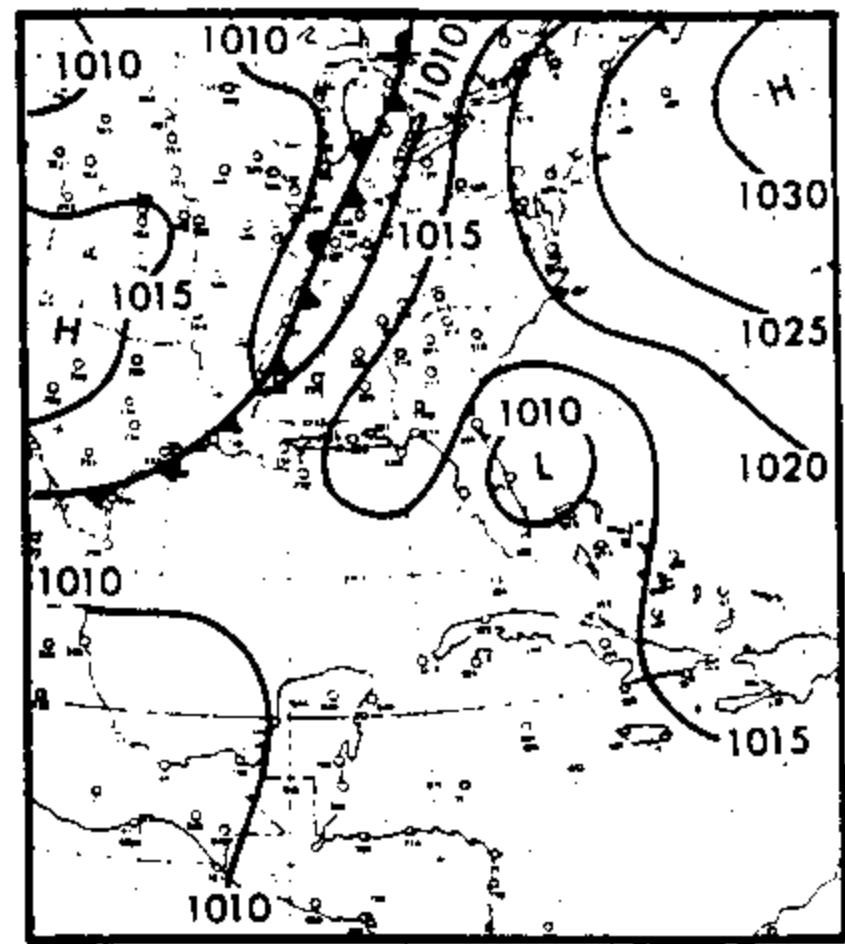


Oct. 1, 1944 Sea Level 1230 GMT

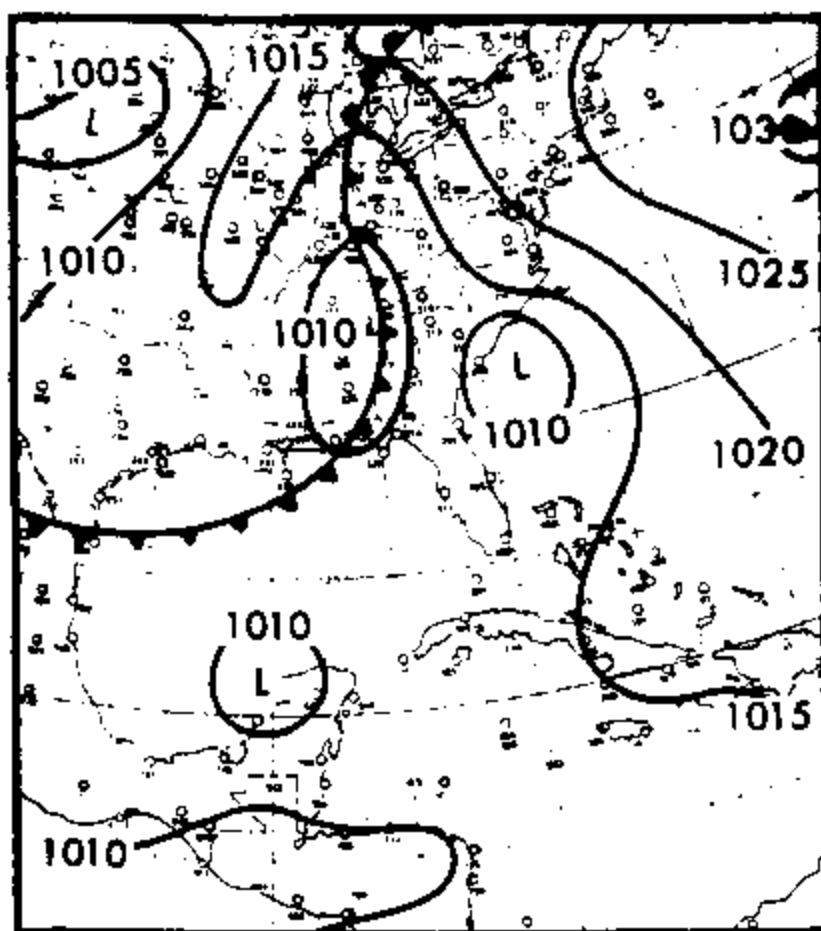
Figure 9.—Surface weather maps for September 28–October 1, 1944.



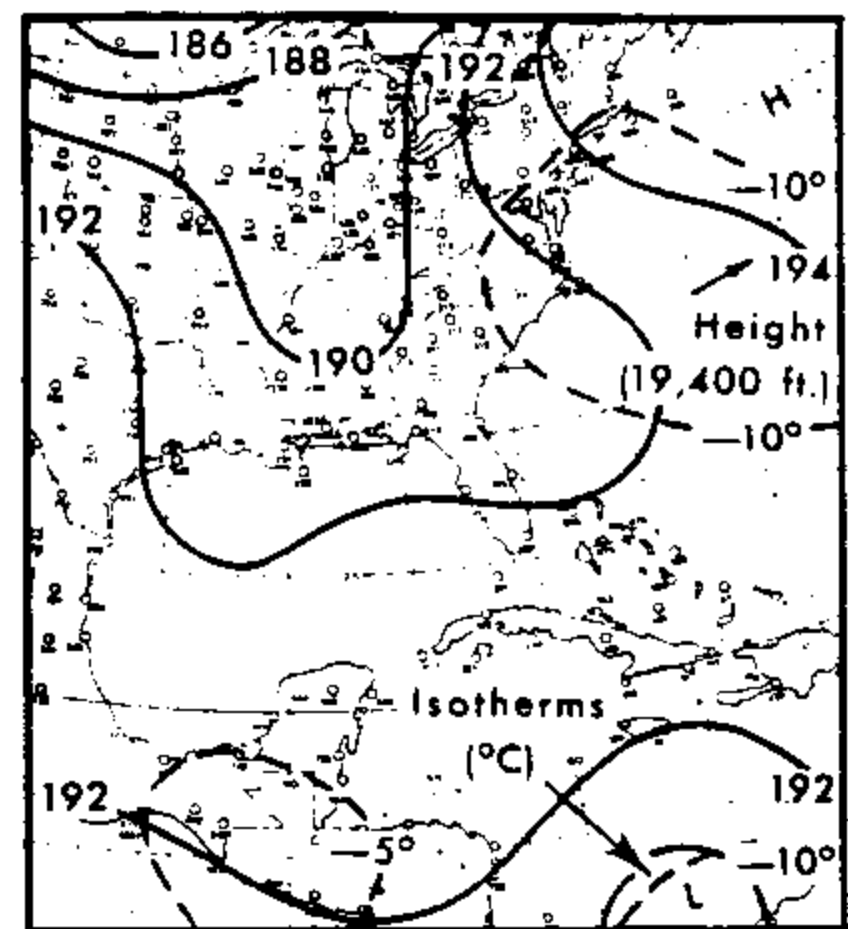
June 14, 1949 Sea Level 1230 GMT



June 15, 1949 Sea Level 1230 GMT



June 16, 1949 Sea Level 1230 GMT



June 16, 1949 500 MB 0300 GMT

Figure 10.--Surface and upper-air weather maps for June 14-16, 1949.

**Table 3.--Storms producing maximum 24-hr rains simultaneously at stations in and near the Tennessee River watershed.**

Storm Date	No. of Stations
August 13-14, 1940	16
August 29-30, 1940	16
Sept. 27-30, 1944	28
June 27-29, 1947	5
June 15-16, 1949	11
October 30-31, 1949	7
March 21-22, 1955	4
March 11-12, 1963	7
Sept. 28-29, 1964	6

Tennessee River watershed in the transition seasons, it is at these times that one is more apt to find a greater number of storms that have the "longer-lasting" characteristic of the summer PMP-type storm. Thunderstorms are involved in these transition season storms, but their rain-producing capabilities are somewhat limited by not being able to draw upon moisture values as high as is possible in midsummer.

An example of a late-fall storm which produced intense rainfall values is that of November 18-19, 1957 (Kleinsasser 1958). This storm produced 9 in. of rain in 2 hr (table 1) over 200 mi<sup>2</sup>. The moisture charge, instability and air-inflow rate in this storm were similar to those in other heavy rain-producing situations. A slowing of the movement of the squall line apparently resulted in an unusual concentration of heavy rain by prolonging the rainfall in a fixed area. Such a storm, though a late-season one, embodies features of the PMP storm type, since intense thunderstorm produced rains were part of a longer-lasting and larger rainfall area.

The Tennessee River watershed lies far enough north that mechanisms for rain production such as squall lines common in the transitional season are also possible (although much less frequent) in the midsummer months. When one or more such "mechanisms" operates in summer over a geographically-fixed area, with moisture near maximum, a Smethport type PMP storm may be the result.

#### **2.1.6 Thunderstorm Climatology and the Diurnal Character of Thunderstorm Rainfall**

The PMP thunderstorm day is envisioned as continued repetition of thunderstorms throughout a 24-hr period. Such a situation requires a continued transport of high moisture into the area of thunderstorm activity and a near stationary triggering mechanism. For the Tennessee River basin, high moisture would generally require winds with a southern component since the moisture source is the Gulf of Mexico. For some areas, such as the westward-facing slopes of the Smokies in Virginia, a more indirect influx of Gulf of Mexico moisture by-passing the mountains and then veering to come from a westerly direction would provide the most effective utilization of existing ground slopes.

A summation of thunderstorm statistics for typical stations in the basin helps to clarify certain characteristics of the PMP type of thunderstorm situation.

Consideration of only summer data on thunderstorms can be misleading. Figure 11 shows the average monthly variation of thunderstorm days at selected Tennessee stations. Data on thunderstorms at Oak Ridge were not available beyond 1964. Figure 12 shows the average daily amount of rainfall on days with thunderstorms for these same stations. The less frequent cooler-season storms which show more average daily rain are in one sense more typical of the PMP type since the cooler-season thunderstorms occur in longer duration rain situations.

#### **2.1.6.1 Diurnal Variation of Thunderstorms as Related to the PMP-Type Storm.**

Most thunderstorms in the eastern United States occur in the afternoon or evening. However, this diurnal variation does not necessarily apply to the PMP type. Most afternoon thunderstorms last an hour or less, and even the extreme ones generally last less than 3 hr. Studies (Changnon 1968, Sangster 1967, and Bonner et al. 1968) emphasized the complexity of the diurnal variation of thunderstorm problems as related to extreme rainfall.

Most Tennessee River watershed summer thunderstorms (those summarized in fig. 11 and 12) are of the insolation, short-lived type. Insolation, or solar radiation received at the earth's surface, is the mechanism often given as the cause of isolated local thunderstorm activity. One trend that can be found in the Tennessee River watershed thunderstorm data is the decrease in importance of the insolation factors as the intensity and longevity of the thunderstorm increase.

**2.1.6.2 Chattanooga Thunderstorm Diurnal Characteristics.** The hourly distribution of precipitation for Chattanooga was summarized for all thunderstorm days in the March-October season during the 1955-1982 28-yr period. A threshold of at least 0.5 in. of rain in a 24-hr period was required to make the data meaningful. Figure 13A summarized the frequency of occurrence of 0.25 in. in any hour for all cases with a daily total of 0.5 in. or more, while figure 13B does so for cases with daily rainfall amounts of 2 in. or more. A decreased effect of the diurnal heating factor is suggested as the heavier rainfall cases are considered. This trend away from the importance of insolation as the thunderstorm intensity increases becomes more evident as one considers the most extreme occurrences.

**2.1.6.3 Diurnal Characteristics of Extreme United States Rains.** The Tennessee River watershed storm of June 13, 1924 (table 1) began before midnight and lasted into the early morning hours. The storm of July 26, 1960, at Grizzle Creek, GA, occurred mostly between 10 p.m. and 1 a.m. Study of the Smethport, PA storm of July 17-18, 1942, indicates that most rain in this storm occurred between midnight and noon. Thus, the usual diurnal characteristics of thunderstorm rainfall appear to be lost in the really big summer thunderstorms. Atmospheric mechanisms contributing to the fixing and prolonging of the rain assume more importance in such storms so that the diurnal heating effect is overwhelmed.

A study was made of the hours of occurrence of the intense rainstorms listed in table 2. Although many of these rains started as showers in the afternoon, the modal time was from 1 to 2 a.m. Since this sample included storms from the Plains states, where nocturnal thunderstorms are common (Means 1952), separate evaluation was made using only storms east of the Mississippi River. Results were similar, with 2 to 4 a.m. being the modal time of rainfall occurrences. These extreme rains more nearly represent the PMP storm type in terms of the loss of afternoon diurnal control. Because of the nocturnal frequency of such storms,

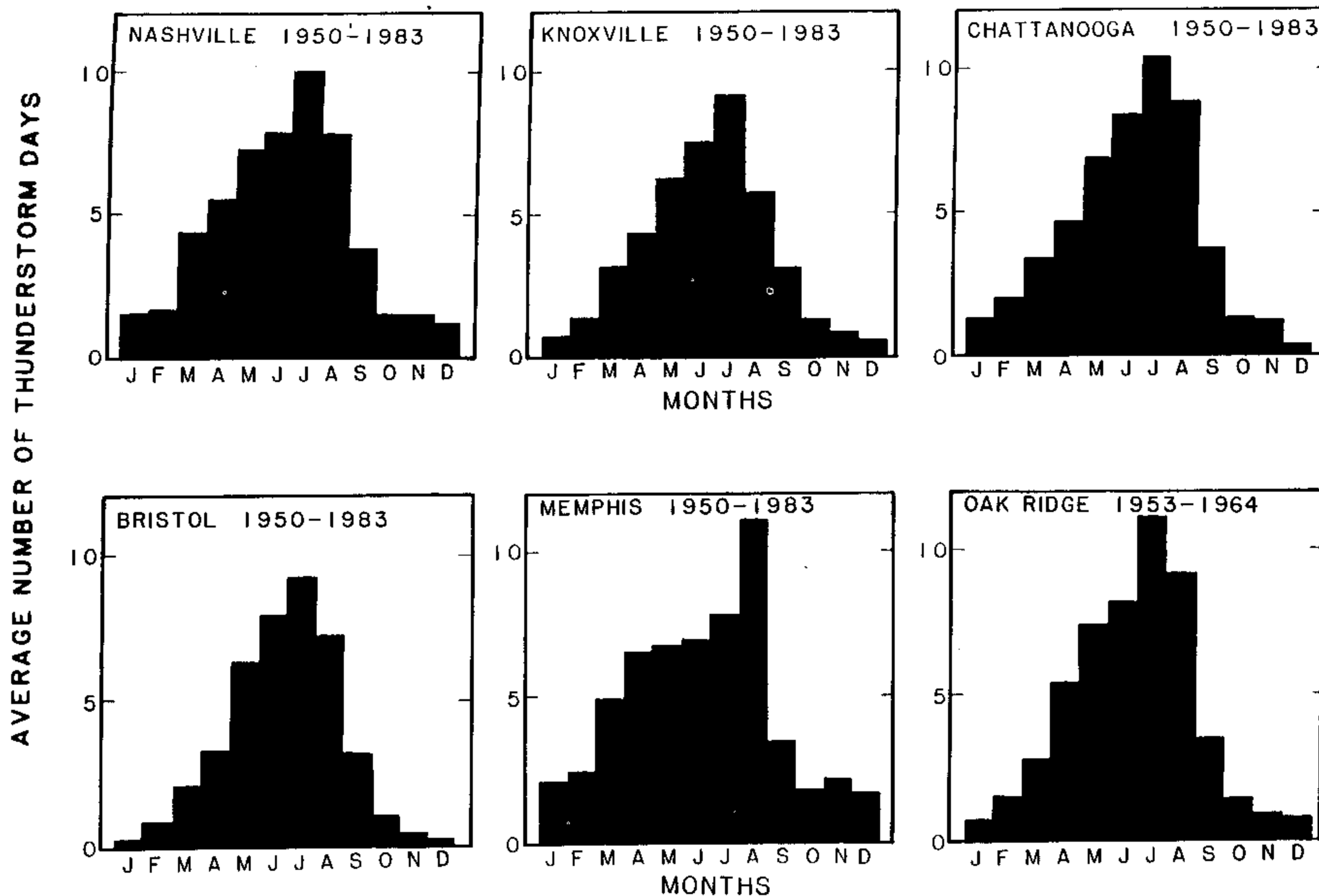


Figure 11.--Monthly variation of thunderstorms at Tennessee stations.

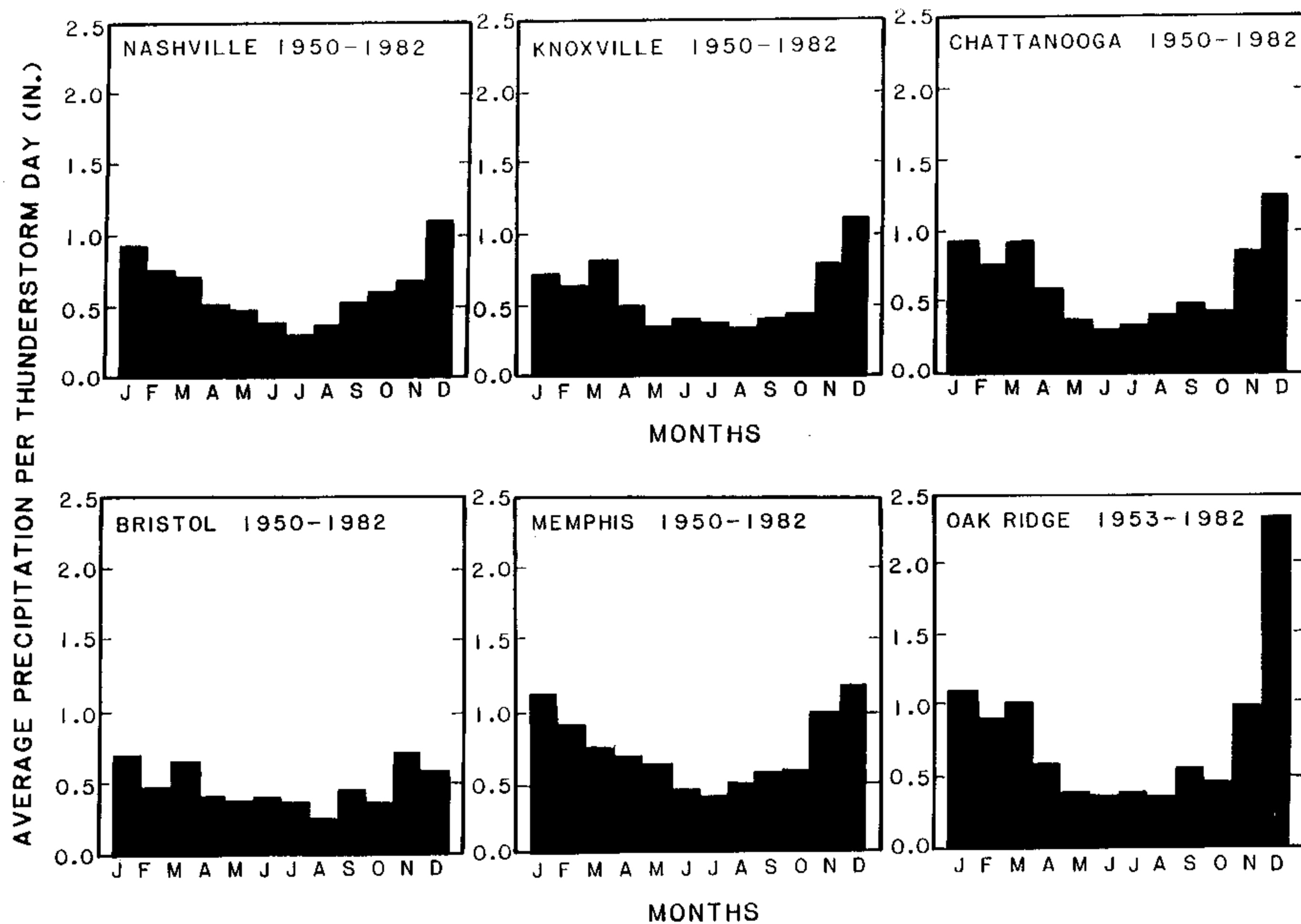


Figure 12.--Monthly variation of average daily precipitation on days with thunderstorms.

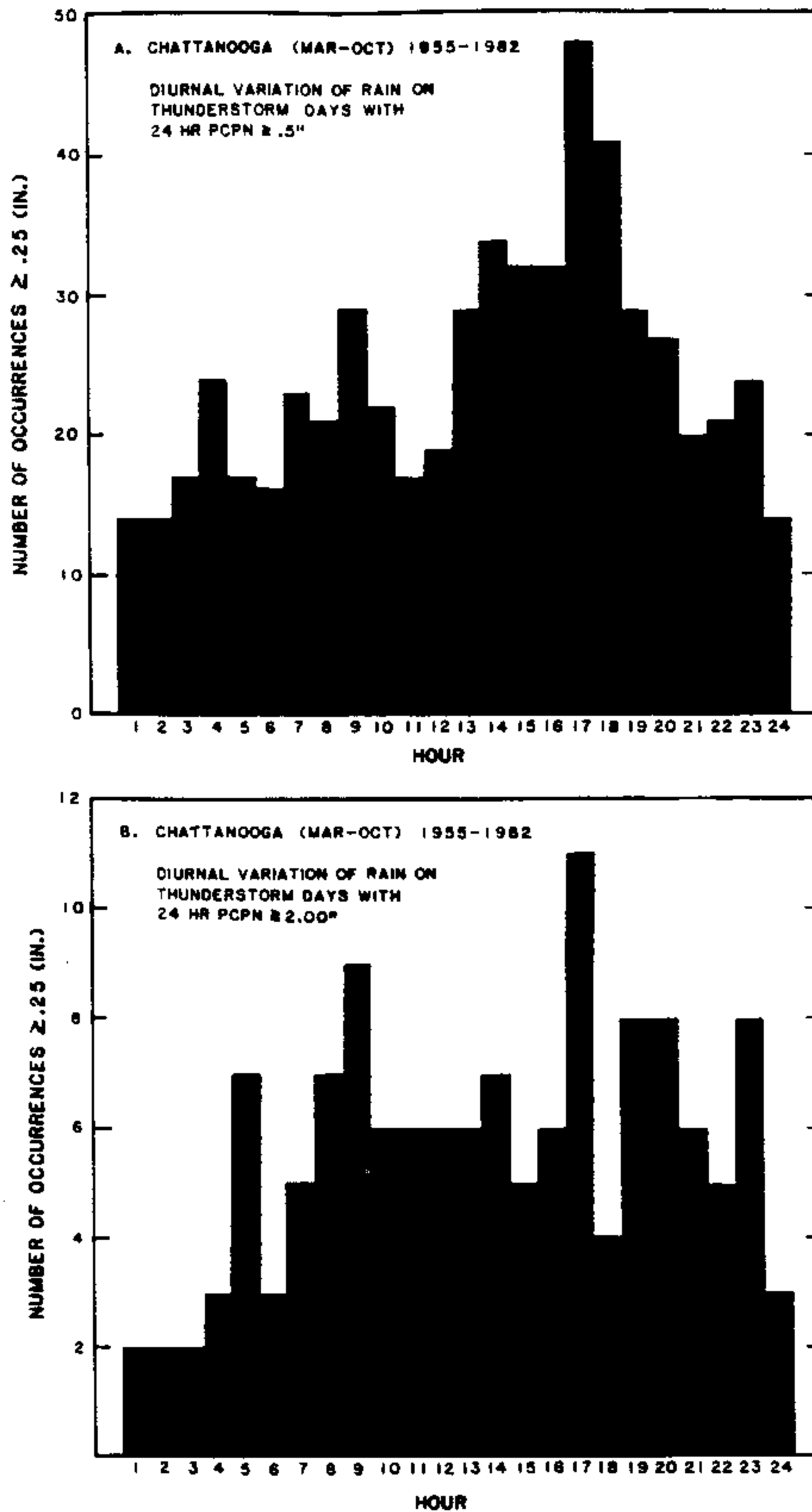


Figure 13.--Diurnal variation of the thunderstorm rainfall at Chattanooga on days with (A)  $\frac{1}{2}$  in. or more and (B) 2 in. or more.

a convergence mechanism that overwhelms insolation and other influences appears to predominate in the more extreme rains and in the PMP storm, especially.

**2.1.6.4 Conclusions on Diurnal Characteristics.** We conclude from the discussion above that the diurnal characteristics common to many thunderstorms both in and outside the Tennessee River watershed does not need to be adhered to in the PMP situation. In the PMP and the TVA storms, the rainfall will extend through and perhaps maximize during the nighttime hours. In the procedure that follows in this and subsequent chapters, allowance is partially made for the more characteristic abbreviated thunderstorm by allowing a TVA level thunderstorm to prevail for as short as 3 hr.

#### **2.1.7 Joining of Thunderstorms as Related to PMP-Type Storms**

Eyewitnesses typically describe extreme rain situations in terms of two or more clouds (storms) "coming together." Table 4 compiled from TVA storm-survey files, summarizes a group of eyewitness accounts of such storms which have occurred in Tennessee and nearby states. These observations are not necessarily restricted to daylight hours since the frequency of lightning in extreme rainfall occurrences permit such observations at night. The use of infrared satellite photos also permit such observations at night. The merging phenomenon, which has also been observed by radar, occurs rather frequently, judging from the reported observance of such occurrences.

Outstanding storms in other parts of the country that involve merging of cloud cells have been similarly described by eyewitnesses. For example, eyewitnesses of a storm near Morgan, UT, on August 16, 1958, that reportedly produced 7 in. of rain in an hour, stated that two clouds appeared to meet right over the valley. Another example is quoted from the observers' notes after a Campo, CA, storm of August 12, 1899, in which an estimated  $11\frac{1}{2}$  in. occurred in 80 min; "... and then another cloud came up and the one that had part passed [sic] over drew back and the two came together [sic] and it poured [sic] down whole watter [sic] nearly." Another observer had this to say about the Catskill, NY storm of July 26, 1819, which dumped 18 in. of rain in  $7\frac{1}{2}$  hr:

"...about half past 5 another dense and black cloud accompanied by a fresh wind arose from the southwest. About the same time or immediately after, a very thick and dark cloud rose up rapidly from the northeast. They met immediately over the town."

Eyewitnesses of the outstanding Smethport, PA storm also spoke of stupendous masses of clouds approaching the area from several directions. Fritsch and Maddox (1981) discuss the changes in winds produced by large mid-latitude convective complexes. They concluded that the changes in the winds in the troposphere and lower stratosphere are rather substantial. In addition, these convective systems could also influence the structure of subsequent convective cloud growth.

Two things were noted about these accounts. First, they usually refer to thunderstorm occurrences in areas that have hills and valleys in close proximity. Second, they concern thunderstorm situations that produced unusually heavy rains.

Table 4.--Storms in the Tennessee River watershed with eyewitness accounts of two storms meeting or coming together

Location	(Coordinates)	Date	Description
Saltville, VA	36°53' 81°46'	7/5/36	"...two storms came together and one man said he thought--- three storm clouds...all came together at the same time"
Speer Ferry, VA	36°39' 82°45'	7/17/36	"...apparently two clouds met, one approaching from the North and the other from the west"
Bulls Gap (nr.) TN	36°15' 83°05'	7/30/37	"...described the storm as the meeting of 3 or 4 clouds from as many directions"
Hayesville (nr.) NC	35°05' 82°50'	7/7/38	"...observed the approach and meeting of two rain clouds, one from the NW and one from the east"
Winchester Springs (nr.) TN	35°14' 86°06'	7/8/38	"...rain came from two clouds, one approaching from the east and one from the west, which met just north of his house"
Lebabon, VA	36°54' 82°05'	5/25/39	"...two storm clouds approached from opposite directions, one from the SW and the other from the NE..."
Adamsville, TN	35°14' 88°24'	6/7/40	"...rain came from two clouds, one moving in and from the SW and one from the NW"
Rogersville, AL	36°22' 83°03'	7/8/40	"...and heavy rain lasted about 1 hr and resulted from the meeting of two clouds, one moving from the SW and one from the SE"
Sparta (nr.) TN	35°55' 85°28'	6/4/49	"The clouds appeared to meet (from east and west) at the top of Little Chatnut mountain..."
Dillard, GA	34°58' 83°55'	6/5/52	"...2 storms, one approaching from...the SW...and the other from...the NE, converged...just south of Dillard"
Grizzle Creek, GA	34°33' 84°04'	7/26/60	"Two clouds moved in from two different directions and met over this area and "the bottom dropped out"

One may conjecture on the meaning of such eyewitness accounts in connection with outstanding cloudbursts. It is possible that the nearly simultaneous occurrence on nearby slopes of two separate thunderstorms sets the stage. With the two gravity-aided cold outflows racing downhill, the resulting convergence sets off a new and more vigorous convective development as the two outflows approach or intermingle. The new thunderstorm development takes over, and the surrounding inflow entrains (pulls) the remnants of the initial thunderstorms into the new development. The new thunderstorm would presumably be extremely efficient since it would entrain into itself not only moist air (minimizing evaporation losses) but also residual, previously formed raindrops. This makes possible local rainfall rates of a magnitude exceeding rates computed by the usual theories which relate the convergence of water vapor to precipitation.

The discussion above has some bearing on the adoption of a storm similar to the one that occurred at Smethport as the PMP storm type for the Tennessee River watershed. The question arises as to whether such a storm is possible to the fullest extent throughout the Tennessee River watershed. Since it has been observed that the "clouds-coming-together" phenomenon is characteristically reported in areas with hills and valleys in close proximity, it apparently would not be realistic to postulate the occurrence of the Smethport type storm unadjusted in very flat regions. Therefore, a geographical distinction is made in applying the PMP-type storm (sect. 2.2).

#### **2.1.8 Season of Small-Area PMP and TVA Precipitation**

The discussion in sections 2.1.4 and 2.1.5 of major storms in the eastern United States suggests that major thunderstorms in the Tennessee Valley are likely to come from warm-season type events. The major events listed in both table 1 and 2 show that the greatest incidence of such storms occurs during the period of June through August. In particular, the more significant small-area storms of Smethport, PA and Holt, MO, occurred in July and June, respectively.

For small-area PMP and TVA precipitation in this report, the three months of June-August represent the all-season maximum. Support for this conclusion is based on the seasonal studies done to develop HMR No. 33 (Riedel et al. 1956) and HMR No. 53 (Ho and Riedel 1980). Both studies apply to small-area PMP, and the storm data mentioned above supports using the same period for TVA precipitation.

#### **2.1.9 Conclusions on PMP-Type Thunderstorms for the Tennessee River Watershed**

The discussions in this section suggest the following conclusions:

1. The candidate small-basin type storm for the Tennessee River watershed is of the thunderstorm variety. This storm will most likely occur during the warm season (May-September). However, these storms may occur as early or as late as the so called "transition" months of March-April and/or October-November.
2. In summer, the small-area PMP storm situation will involve a continuation of thunderstorms, fixed geographically, throughout a period lasting up to 24 hr.

3. The summer PMP-type thunderstorm will likely depart from the usual diurnal characteristics of thunderstorms in and near the Tennessee River watershed. The role of diurnal heating will be minimized if the maximum rainfall rates occur during the nighttime hours as in the important Smethport storm.
4. The summer PMP-type thunderstorm will be capable of producing more rainfall in some geographical area (e.g., slopes and valleys in close proximity) than in others (e.g., very flat areas with no nearby slopes).

## 2.2 Derivation of PMP and TVA Precipitation Values

### 2.2.1 Introduction

This section discusses the determination of the magnitude of summer PMP and TVA precipitation over small basins. In conforming to the definitions adopted in chapter 1, the rarest known storms with moisture maximization and transposition are guides to defining the PMP level, while the TVA precipitation level is based on storms as observed without moisture maximization and with undercutting of the most extreme events. Maps were derived showing 6-hr 1-mi<sup>2</sup> PMP and TVA precipitation. Depth-area and depth-duration relations were developed for use with these maps to give the extreme precipitation values for other durations up to 24 hr and basin sizes up to 100 mi<sup>2</sup>. For the TVA level of precipitation, a family of variable depth-duration curves is provided. An important aspect of the study is the evaluation of topographic factors and their influence on rainfall.

### 2.2.2 Data

The basic storm information used to determine the short-duration PMP and TVA precipitation are the outstanding storms that occurred in or near the Tennessee River watershed (table 1) and the similar storms which occurred elsewhere in the country (table 2). The most important of the storms outside the Tennessee River watershed was the Smethport, PA storm of July 17-18, 1942.

### 2.2.3 Topographic Classification

Topography is known to play an important role in rainfall in the Tennessee River watershed. The problem is to develop a meaningful broadscale classification system that can be related to the occurrence of intense storms. One means of assessing topographic factors is from inspection of topographic maps. The Tennessee Valley watershed has been completely mapped to a scale of 1/24,000 on 7 1/2 min quadrangles, with 20-ft contours.

From topographic map inspection, the decision was made that PMP and TVA precipitation estimates should be developed for three classifications of terrain. These were "smooth," typified by the area around Columbia, TN (fig. 1); "rough," typified by most of the Blue Ridge Province; and "intermediate," for which the area around Knoxville is an example. Each quadrangle map in the Tennessee River watershed was classified "smooth," "intermediate," or "rough," in accordance with the following rules:

"Smooth," if there are few elevation differences of 50 ft in 1/4 mi.

"Intermediate," where elevation differences from 50 to 150 ft within 1/4 mi are frequent.

"Rough," if there are general areas with elevation differences exceeding 150 ft within 1/4 mi.

Single isolated mountains or hills did not warrant a rough classification. In areas of narrowing "V"-shaped valleys, elevation differences of less than 150 ft were given a rough classification, based on the idea that this type of land form favors convergence of the air and lifting. For extensive mountain chains or ridges, the rough classification was extended out 3 mi or so away from the mountain.

Under this classification system all of the eastern mountainous part of the Tennessee River watershed is designated as "rough." For the western part of the watershed the classifications of the individual quadrangle maps were noted on a master map of the basin, and a single map constructed dividing the region into the three topographic classes and smoothing (see fig. 67 and 68).

#### **2.2.4 Orographic Effects in the Eastern Blue Ridge-Appalachian Region**

Although the eastern portion of the Tennessee River watershed was classified as "rough," this did not adequately explain the variations in rain potential across the region. In some places mountains extend to 6,000 ft above mean sea level. In other places large valleys are sheltered by mountains. This contrast between high mountains and large sheltered valleys required additional consideration besides "roughness" in order to fully assess the orographic effects on intense summer rains.

As an aid to delineating orographic effects, maps of 2-yr and 100-yr return period daily rains were constructed. This was done using all rainfall stations with 15 or more years of record as of 1973. After some consideration, the following concepts evolved and were adopted:

**First upslope:** This is defined as a mountain slope facing the lowlands in a direction east through southwest with no intervening mountains between the slope and the Gulf of Mexico or the Atlantic. In general, total summer precipitation on first upslope areas is around twice that of sheltered areas.

**Secondary upslope:** A secondary upslope is high and steep enough to increase precipitation, but is partially shielded upwind (toward moisture source) by a lower mountain range, with an elevation difference between the crests of at least 1,500 ft. Total summer precipitation on secondary slopes is 30 to 50 percent greater than that of sheltered areas.

**Sheltered areas:** These are defined as valleys having upwind barriers from southeast through southwest of 2,000-ft elevation above sea level or higher.

**Depression:** The elevation difference between the crest of a barrier and a point within a sheltered area is the "depression" at that point.

A map showing these orographic categories is shown in figure 14. Some smoothing has been done based on both inspection of topographic maps and rainfall behavior. For example, some portions of the Ocoee Basin, while technically "sheltered" by the above definition, according to the rainfall experience of the area, are effectively "first upslope."

**2.2.4.1 Adopted Variation of PMP and TVA Precipitation.** The following guides are adopted for orographic influence on PMP and TVA precipitation in the eastern portion of the basin:

Precipitation increase of 10 percent per 1,000 ft from sea level up to 2,500 ft on first upslopes with no further increase above 2,500 ft.

Precipitation increase of 5 percent per 1,000 ft from sea level to all elevations on, secondary upslopes.

Five percent decrease per 1,000 ft of depression in sheltered areas.

## **2.2.5 Broadscale Sheltering Effects**

In the mountainous east portion of the watershed, inflow directions from the south to southwest will affect moisture as it occurs from the southern to the northern edge of the mountainous east. This depletion of moisture will in turn cause a decrease in rainfall potential south to north and is caused by the sheltering effects of the mountainous east terrain. The amount of decrease and how it was derived is explained further in section 2.2.8 and is shown in figure 18.

Rainfall indices, such as 2-yr 24-hr precipitation (see fig. 59), suggest such a broadscale sheltering effect, increasing northward, as interference to moisture inflow by the mountains increases. The suggested decrease amounts to about 10 percent from the Ocoee Basin northeastward to the South Holston Basin (see fig. 18).

## **2.2.6 TVA Depth-Duration Curves for 1 mi<sup>2</sup>**

Following the concept of "TVA precipitation" expressed in the introduction to this report (sect. 1.4), the TVA storm for small basins is based on depth-duration curves of observed extreme point rainfalls. The 19 heaviest rainfalls from the list of Tennessee River watershed storms (table 1) are plotted in figure 15, with the storm identification number. The storm rainfall depths given in table 1 were for the maximum storm area for which data were available. The storm data were analyzed using standard procedures (WMO 1973) to develop 1-mi<sup>2</sup> depths. For those storms where only single station or "point" values were available, these values were considered equivalent to average depths over 1 mi<sup>2</sup>. Thus, the depth-duration curves in figure 15 apply to an area of 1 mi<sup>2</sup>. Added to the plot are the Simpson, KY storm of July 1939 and the Glenville, WV storm of August, 1943. The topographic classification for each storm site is indicated.

Enveloping depth-duration curves for "rough" topography and "smooth" topography were constructed applying the following concepts and principles.

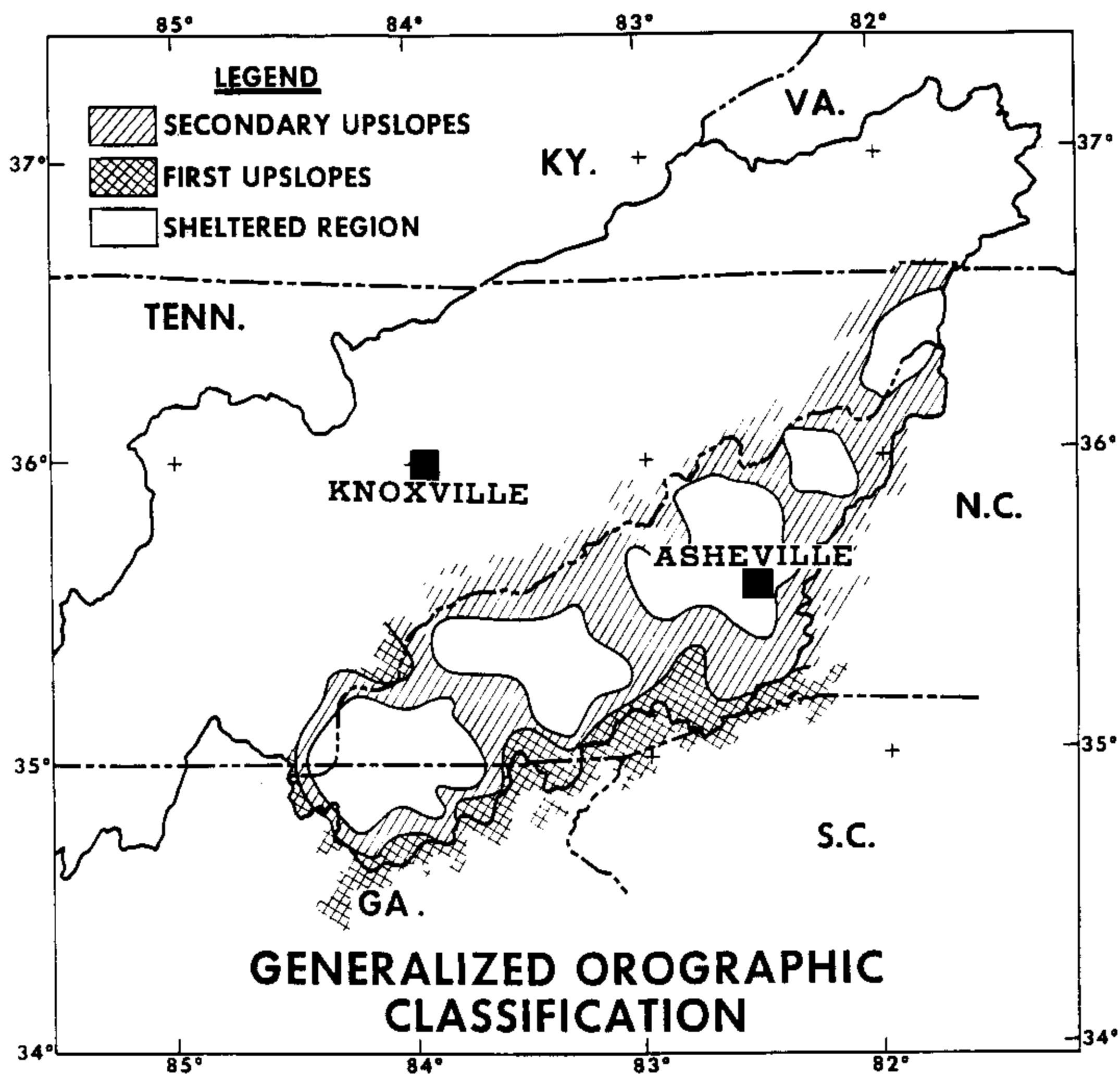


Figure 14--Orographic classifications of the mountainous eastern portion of the Tennessee River watershed.

- a. The effect of topography increases in relation to the dynamic effects of the atmosphere during the course of the storm. Since vertical velocities imparted to the air as a result of wind flow against slope remains relatively constant, it plays a less significant role in production of precipitation during the most intense part of the storm than during the remaining time rainfall occurs. Thus, when comparing depth-duration curves over "smooth" and "rough" terrain, a continuous divergence can be expected from hour zero to the total duration of the storm.
- b. "Rough" terrain and mountain slopes tend to "fix" the thunderstorm causing the rain to continue over one location for a longer period than over "smooth" terrain where the storm would drift more randomly with the upper level wind, or propagate laterally by its own dynamics. Thus for longer durations, the probability of continued rain after an unusual thunderstorm is enhanced by favorable topography.
- c. The TVA-level extreme precipitation corresponds to the largest values that have been observed in the region (without moisture maximization), except that spectacular events that are extreme "outliers" have been undercut. Of the data plotted in figure 15, only the value for Simpson storm falls in this latter category and is undercut. The Simpson storm is considered transposable to some portions of the Tennessee River watershed. The curve for "rough" is drawn through the middle of the range of values (table 1) for storm 37 and envelopes the other storms that have occurred over "rough" terrain in Tennessee. The "smooth" depth-duration curve is drawn through storm number 7 at 3/4 hr.
- d. Examination of storms in the Tennessee Valley and surrounding regions indicated a ratio of 0.67 between 1- and 3-hr amounts and 0.80 between 3- and 6-hr amounts would be characteristic of the type of storm capable of producing TVA precipitation. These ratios were used to extend the smooth curve beyond the value indicated by storm number 7. Both depth-duration curves were extended from 6 to 24 hr (dashed) using the relation shown in figure 17 (sect. 2.2.7.2).

To determine the intermediate depth-duration relation for TVA precipitation, simply average the rough and smooth relations given in figure 15.

#### 2.2.7 PMP Depth-Duration Curves for 1 mi<sup>2</sup>

Prior to the preparation of HMR No. 45, Hydrometeorological Reports did not distinguish between point rainfalls and average depths over 10 mi<sup>2</sup>. Values determined for the 10-mi<sup>2</sup> area were treated as equivalent to point values. When HMR No. 45 was prepared, it was felt that greater refinement was needed, and data would permit PMP estimates for smaller areas to be developed. Consequently, storm data was used in HMR No. 45 to develop depth-duration curves and depth-area-relations that were applicable to a 5-mi<sup>2</sup> area (see, for example fig. 2-15 and 2-23 of HMR No. 45). In HMR No. 51, it was recognized the PMP

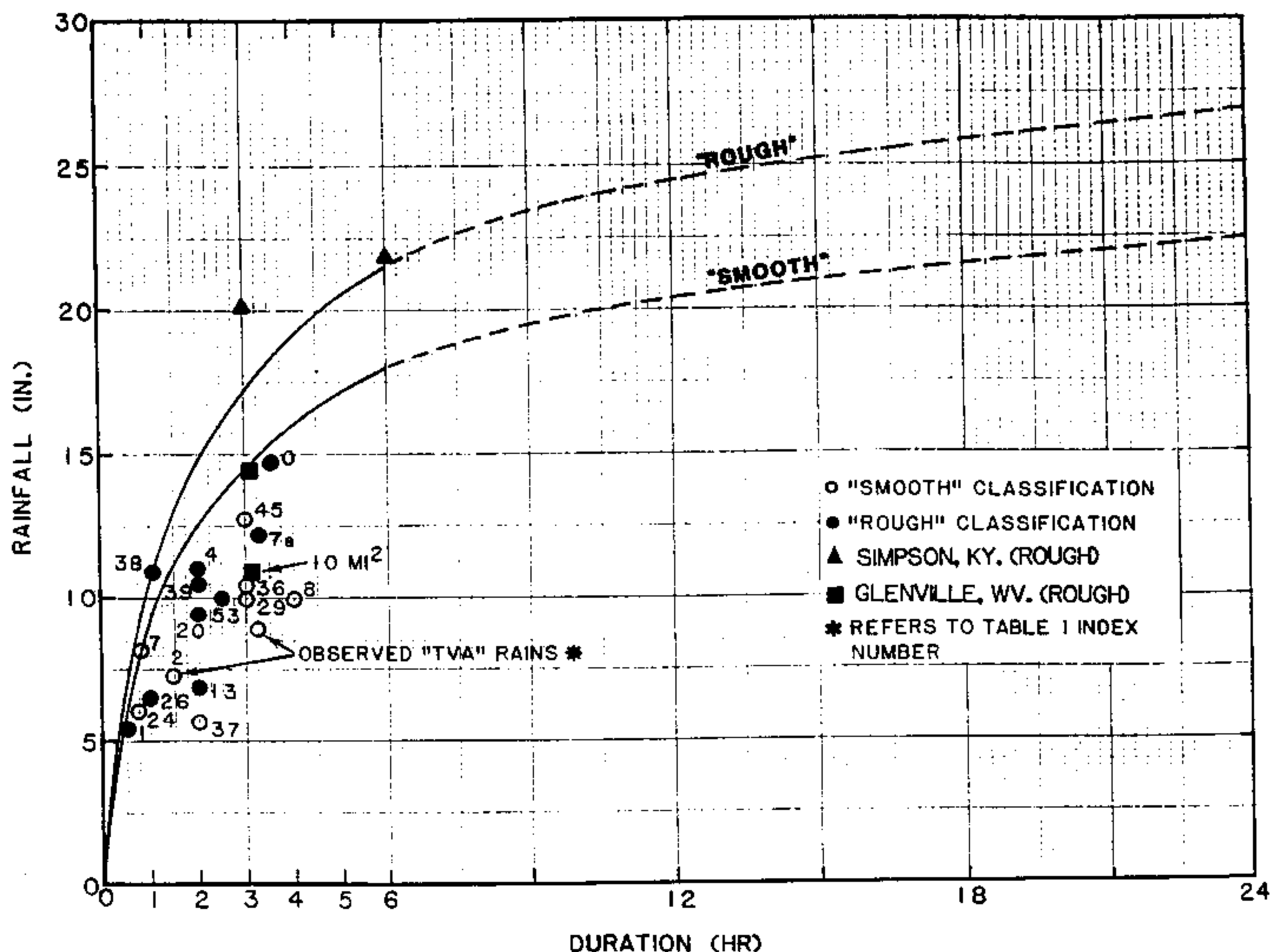


Figure 15.--Adopted 1-mi<sup>2</sup> TVA precipitation depth-duration curves with supporting data.

estimates for areas less than 10 mi<sup>2</sup> would be larger than the values shown on the generalized charts. In development of HMR No. 52, 1-hr PMP values were determined for 1 mi<sup>2</sup>. Therefore, it was considered desirable to develop depth-duration relations in the present study, based on the use of 1-mi<sup>2</sup> (point) storm data. In order to derive these 1-mi<sup>2</sup> estimates, the transposition and moisture maximization method as described in HMR No. 45 and 51 was used.

**2.2.7.1 Development of Curves for Durations of 6 hr and Less.** From table 2, storms were selected and maximized, transposed and enveloped to obtain depth-duration curves for rough and smooth terrain. Two storms from this selection were particularly significant in defining the shape of these curves; the Smethport, PA storm of July 17-18, 1942, representing the "rough" category, and the Holt, MO storm of June 22-23, 1947, representing the "smooth" curve. The following considerations were involved in developing the depth-duration envelopes for durations up to 6 hr (solid lines) shown in figure 16.

- a. Smethport storm adjustment factors were computed for maximum moisture (using a maximum persisting 12-hr 1000-mb dew point of 76°F and representative persisting 12-hr storm dew point of 74°F) and transposition (using a transposed maximum persisting

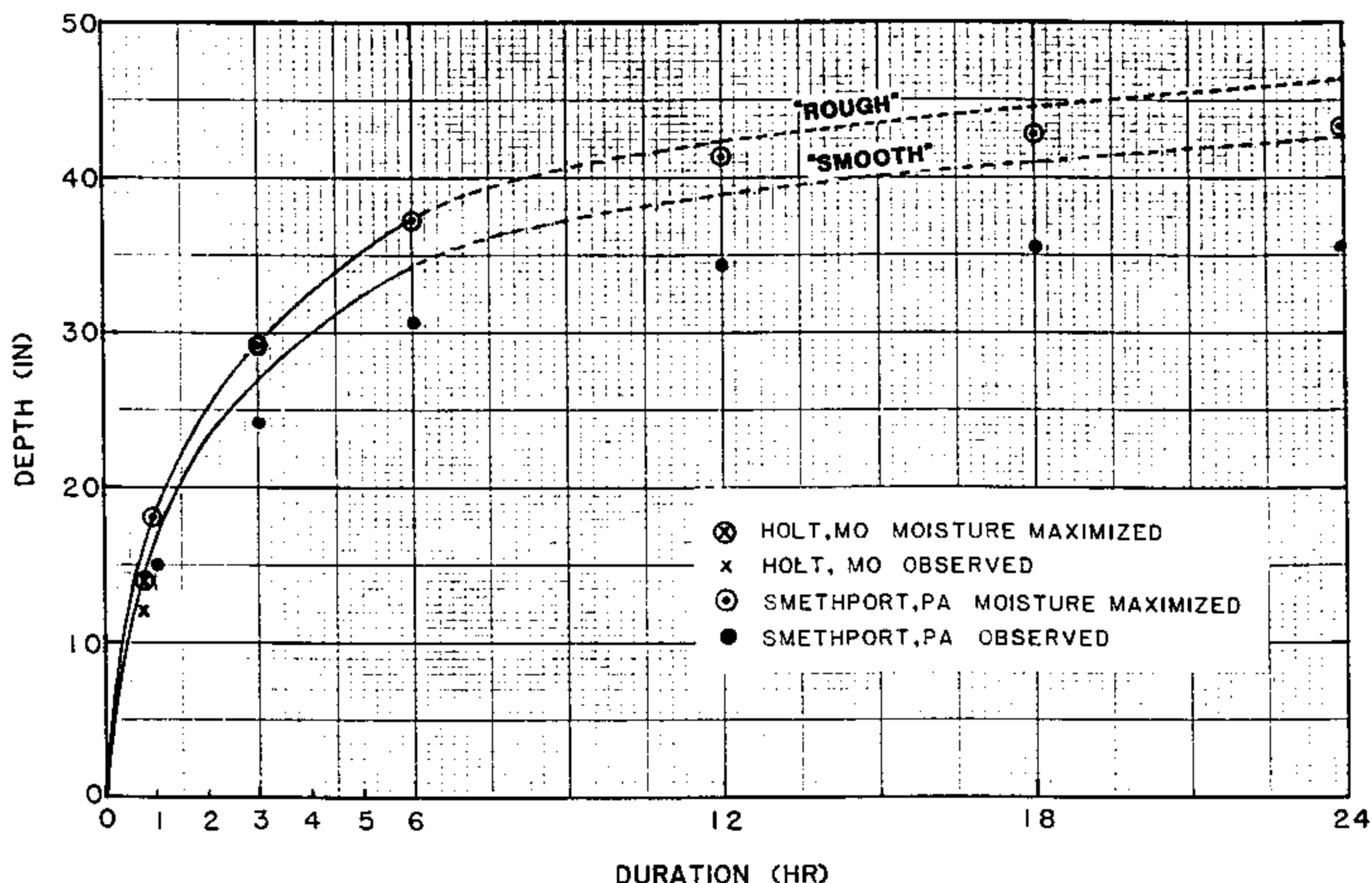


Figure 16.--Adopted 1-mi<sup>2</sup> PMP with supporting data.

12-hr dew point of 78°F). This resulted in a combined adjustment factor of 1.22, which was used to adjust the 1-mi<sup>2</sup> observed storm values of 15.0, 23.0, and 30.7 in. at 1, 3, and 6 hr, respectively. The 1-hr value was determined in the preparation of HMR No. 52 and is discussed in that report. The 3-hr and 6-hr values were obtained from maximum station data relations from analyses in Storm Rainfall in the United States (U.S. Army Corps of Engineers 1945- ), rather than the amount at 4.5 hr that was used in figure 2.15 of HMR No. 45. This change from use of the 4.5 hr duration to 1, 3 and 6 hr was made to make intercomparisons consistent between this report and other reports in the HMR series and has no effect on the results. Values from other storms in table 1 or 2 moisture maximized to a persisting 12-hr 1000-mb dew point of 78°F did not exceed those for Smethport. Because the site of the Smethport storm is classified as "rough" under the topography classification system described in section 2.2.3, the enveloping curve in figure 16 is considered applicable to "rough" sites in the Tennessee River watershed.

- b. The short duration Holt, MO storm amount of 12.0 in. in 42 min was moisture maximized and transposed, using a maximum dew point of 78°F and a representative persisting 12-hr 1000-mb storm dew point of 75°F, for a combined adjustment factor of 1.20. This is different from the procedure used in

HMR No. 45. In HMR No. 45, the Holt storm was not moisture maximized when transposed to the Tennessee River watershed. The reason for omitting moisture maximization was based on differences found in thunderstorm and tornado frequencies between the midwest and over the Tennessee River watershed. However, recent studies, e.g., Technical Memorandum NWS HYDRO 35 (Frederick et al. 1977), have indicated fewer differences in very short duration precipitation-frequency values between the midwest and Tennessee River watershed. Also, in the development of HMR No. 51, studies indicated the Holt storm should be moisture maximized when it was transposed to the western part of the valley. Therefore, the Holt storm is moisture maximized in this report also. In figure 16, the "smooth" curve envelopes the moisture maximized Holt storm at 42 min (the duration of most intense precipitation).

- c. The "rough" depth-duration curve to 6 hr in figure 16 was developed by envelopment of the moisture-maximized, transposed Smethport values. Similar extremes for durations to 6 hr were not found for storms over "smooth" terrain. It was necessary, therefore, to extend the "smooth" curve beyond 1 hr by indirect methods. In the absence of other information, the same 6- to 1-hr ratio was used for both the rough and smooth curves. This resulted in a 6-hr "smooth" value of 34.4 in.
- d. Although the topographic classification described in section 2.2.3 defines rough, smooth and intermediate terrain, none of the storms in our sample that occurred over terrain classified as intermediate are significant enough when maximized and transposed to represent this depth-duration curve. This curve is established as a simple average of the "rough" and "smooth" curves. The intermediate curve is not shown in figure 16, however.
- e. In HMR No. 45, the ratio between the 6-hr 5-mi<sup>2</sup> TVA and the respective 6-hr 5-mi<sup>2</sup> PMP depth-duration curves was 0.60 for all terrain classes. Comparing figures 15 and 16, these ratios are now 0.58 (rough), 0.55 (intermediate) and 0.53 (smooth) for 6 hr 1 mi<sup>2</sup>. These differences are a result of different maximization and envelopment procedures in the development of the TVA and PMP depth-duration curves between the original HMR No. 45 and the current version. Note that, as explained in section 2.2.7.2 below, the ratios 0.58, 0.55, and 0.53 have been extended through 24 hr and are assumed to be valid through 72 hr. The need for durations between 24 and 72 hr will be important in the large basin procedure (see sect. 5.3) when converting the computed PMP to a TVA precipitation for any basin where the majority of the basin is composed of "rough," "intermediate," or "smooth" terrain.

**2.2.7.2 Extension of Depth-Duration Curves Through 24 hr.** When extending PMP depth-duration curves to longer durations, it is customary to use as a guide the ratio of longer duration to shorter duration precipitation observed in large storms (e.g., HMR No. 41, page 82, Schwarz 1965, and HMR No. 45, page 45, Schwarz

and Helfert 1969). Basic information and features of storms appropriate for this purpose in the Tennessee Valley are:

1. 1-mi<sup>2</sup> data available
2. non-tropical
3. of the thunderstorm variety, i.e., exhibiting a "spike" in the storm's rainfall vs. time curve
4. occurs east of the Rocky Mountains; and
5. occurs during the months of April-September when severe thunderstorm activity is most likely.

The storms listed in table 5 with durations equal to or longer than 12 hr were used in development of the extended depth-duration curve. All storms were used in preparing the depth-area curves discussed in section 2.2.10.

The plotted ratios and the adopted durational curve (solid line) are shown in figure 17. The adopted curve resembles the dashed curve drawn through the mean ratio for 12, 18 and 24 hr. The positive deviation of the adopted curve at 24 hr takes into account the fact that with the PMP storm there is most likely to be a continuation of precipitation at the same location to a greater extent than found in most observed storms (sect. 2.1.1). The adopted depth ratio at 24 hr, 1.24, is .03 larger than the mean ratio of 1.21. The adopted depth-duration curve is drawn through the mean depth ratio at 18 hr and somewhat undercuts the ratio at 12 hr. This curve is viewed to be a "best fit" for data from all durations in this region. The list of storms in table 5 includes storms which occur in both "smooth" terrain (e.g., the Keene, OH storm of August 6-7, 1935) and in "rough" terrain (e.g., the Simpson, KY storm of July 4-5, 1939). Consequently, the adopted relationship in figure 17 applies to the "rough" and "smooth" curves of figures 15 and 16 and to the respective intermediate relations.

The adopted curve of figure 17 together with the 6-hr amounts from figure 16 are used to extend the PMP depth-duration curves to 24 hr in figure 16 (dashed lines). To obtain, for example, the 12-hr 1-mi<sup>2</sup> "rough" ("smooth") PMP value, multiply the adopted 12- to 6-hr 1-mi<sup>2</sup> ratio of 1.13 by the 6-hr 1-mi<sup>2</sup> "rough" ("smooth") value of 37.4 (34.4) and obtain the 12-hr 1-mi<sup>2</sup> "rough" ("smooth") PMP value of 42.3 (38.9) in. These values and similar values for the 18- and 24-hr duration were computed and the extended curves are shown in figure 16. The 12- and 18-hr maximized and transposed Smethport values are also shown on this figure for comparison and support of the adopted curve.

Table 6 lists 1-mi<sup>2</sup> PMP and TVA precipitation values for each of the 3 categories (rough, intermediate, and smooth) for 5-min increments up to 1 hr and for each hour to 24 hr. These values were obtained from figures 15 and 16 and are given to aid interpolation of short duration values by the user.

#### 2.2.8 Adjustment for Moisture Gradient and Latitudinal Gradient

The depth-duration curves for 1-mi<sup>2</sup> PMP and TVA precipitation developed in figures 15 and 16 represent the optimum moisture conditions entering the TVA watershed. A geographic variation over the Tennessee River watershed was based